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METHODS FOR PREDICTING AND ASSESSING THE IMPACT OF TECHNOLOGY ON HUMAN RESOURCE PARAMETERS

REPORT OF THE LITERATURE

SYSTEMS RESEARCH LABORATORIES, INCORPORATED

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A research objective of the Air Force Human Resources Laboratory is the development of methods for defining the components of innovative technology and for measuring the effects of the incoming technology on Air Force human resources. The human resource parameters of concern include manpower (e.g., numbers, job types, skill levels), training considerations, and cost data. Earlier investigations established the feasibility of using human resources data in design trade studies and of determining and graphically depicting the array of trade-off options available before inception of hardware design. The purpose of this review was to establish the current status of the methodology for forecasting and assessing technology and for quantizing human resource parameters with respect to the impact of incoming technologies.

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A search and critical analysis of the literature was undertaken to review the status of forecasting and assessing technology and of techniques for predicting the impact of technology on human resource parameters. The size of the literature base in the area of technological forecasting and technology assessment precluded the conduct of an exhaustive review. Rather, the determination was made that inclusion of selected references which described current methodologies in detail and which were judged as representative would better satisfy the objectives of the research effort.

A total of 140 documents applicable to this effort were reviewed. Seventeen of these were identified as having major significance to the present effort. The review of the literature failed to provide solution to the problem of quantizing human resource parameters with respect to impact of incoming technologies. However, the use of a normative forecasting technique was strongly supported by the literature. In particular, a relevance tree approach was the technique viewed as amenable to the problem of successive identification of increasingly finer components in an organized, structured manner. The relevance tree procedure known as a Design Option Decision Tree was identified as practical for detailing a system to a level permiting the identification and assessment of human resource components for impact quantification.

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This technical report was submitted by Systems Research Laboratories, Inc., 2800 Indian Ripple Road, Dayton, Ohio 45440, under contract F33615-74-C-4019, project 7907, with Advanced Systems Division, Air Force Human Resources Laboratory (AFSC), Wright-Patterson Air Force Base, Ohio 45433. Major Duncan L. Dieterly, Personnel and Training Requirements Branch, was the Laboratory contract monitor.

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This technical report has been reviewed and is approved.

GORDON A. ECKSTRAND, Director
Advanced Systems Division

Approved for publication.

HAROLD E. FISCHER, Colonel, USAF
Commander

SUMMARY

PROBLEM

A research objective of the Air Force Human Resources Laboratory is the development of methods for defining the components of innovative technology and for measuring the effects of the incoming technology on Air Force human resources. The human resource parameters of concern include manpower (e.g., numbers, job types, skill levels), training considerations, and cost data. Earlier investigations established the feasibility of using human resources data in design trade studies and of determining and graphically depicting the array of trade-off options available before inception of hardware design. The purpose of the review reported here was to establish the current status of the methodology for forecasting and assessing technology and for quantizing human resource parameters with respect to the impact of incoming technologies.

APPROACH

A search and critical analysis of the literature was undertaken to review the status of forecasting and assessing technology and of techniques for predicting the impact of technology on human resource parameters. The size of the literature base in the area of technological forecasting and technology assessment precluded the conduct of an exhaustive review. Rather, the determination was made that inclusion of selected references which described current methodologies in detail and which were judged as representative would better satisfy the objectives of the research effort. Emphasis was directed toward location of quantification methods for human resources impact of technological innovations.

Computer-based reference systems of the Defense Documentation Center, National Technical Information Service, Systems Development Corporation and The Ohio State University were employed as integrants to a conventional search of the professional literature.

RESULTS AND CONCLUSIONS

A total of 140 documents applicable to this effort were reviewed. Seventeen of these were identified as having major significance to the present

effort. For these 17, 3-page expanded summaries were generated and appended to this report of the results of the literature survey.

Review of the literature failed to provide solution to the problem of quantizing human resource parameters with respect to impact of incoming technologies. However, the use of a normative forecasting technique was strongly supported by the literature. In particular, a relevance tree approach was the technique viewed as amenable to the problem of successive identification of increasingly finer components in an organized, structured manner. The relevance tree procedure known as a Design Option Decision Tree was identified as practical for detailing a system to a level permitting the identification and assessment of human resource components for impact quantification.

Development of quantizing methods and procedures for evaluating the adequacy of the evolved techniques in generating human resources data for system designers and personnel planners are highlighted as goal directions for the remaining study effort.

PREFACE

This study was initiated by the Advanced Systems Division, Air Force Human Resources Laboratory, Wright Patterson Air Force Base, Ohio, under Project 7907, "Conditions of Effective Training and Transfer," Dr. Ross Morgan, Project Scientist, and Work-Unit 79070007, "Determining Impact of New Technology on Air Force Human Resources," Duncan L. Dieterly, Major, USAF, Task Scientist. The research is being performed by Systems Research Laboratories, Dayton, Ohio, under Contract F33615-74-C-4019 with Dr. Norman R. Potter as principal investigator. The first phase of a multiphased research effort was conducted during the period from 3 December 1973 through 28 February 1974. Scheduled completion of the total effort is 31 August 1974.

The authors wish to acknowledge the guidance and support provided by Dr. William B. Askren and Kenneth W. Potempa of the Personnel and Training Requirements Branch, Advanced Systems Division, in initial structuring of the research problem.

Appreciation is extended to Dr. Joseph P. Martino (Colonel, USAF) for his cooperation and instructive consultation regarding technological forecasting.

Finally, appreciation is expressed to Steven M. Simon and Gary M. Van Wagoner of Systems Research Laboratories for their assistance in this undertaking.

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Section I

INTRODUCTION

The increasing demand to improve the capabilities of new weapon systems entering the inventory of the military is forcing a change in the traditional conceptualization of the man-machine interface and the support requirements of a system. Advanced manpower planning and restrictive budget constraints require the systems planner to refine the projected human resource estimates to result in more optimal employment of the human resource component. It is no longer sufficient to roughly approximate the human resource requirements necessary for operating and maintaining a given weapon system. Since a given weapon system usually integrates technological innovations, it becomes essential to be able to predict the impact of these innovations on human resource parameters. Military management must therefore develop a feasible way to locate and anticipate the advent of technological innovations and predict, in advance, the human resource consequences.

Historical evidence that such an action is necessary when dealing with complex weapon systems can be found readily in prior Air Force procurements. A single anecdotal reference is used for illustrative purposes. In the introduction of the radar gunsight on the F-86 fighter in Korea, maintenance aspects of the subsystem were not given sufficient advance consideration. Consequently, the sight became operational in the field but could not be adequately maintained. A priority effort was undertaken to train existing gunsight repairmen on the new system, a logical decision, since the additional training would be minimal for this group of personnel. Unfortunately, the training was conducted at the manufacturer's plant, an action which effectively removed conventional gunsight repairmen from the field, further compounding an already serious maintenance problem.*

In the present environment, a persuasively compelling argument for reflecting the impact of technological innovation on human resources in the design phase is found in cost considerations. The largest single life-cycle cost in a weapon system is the human resource cost over the period of time

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* Personal observation of the senior author.

the system is in the operational inventory. A system designer must have access to data concerning the human resource parameters relative to various design options in order to select the most effective design based on life-cycle cost considerations.

Eckstrand, Askren, and Snyder (1967) emphasized this need for a detailed consideration of human resources by classifying these resources as an "important design parameter" but cautioned, "unfortunately, the data and technology for (this) involvement . . . have not been developed to the required degree."

In this paper the term technology will be used to describe the area of knowledge that composes the applied techniques used in the production of a weapon system. Therefore, technology would encompass all disciplines involved, e.g., mechanics, electronics, and metallurgy. An innovation will be considered as any new aspect of a given discipline which has potential practical application. What we are therefore seeking is a way to predict the impact of a technological innovation upon the human resource requirements of a specified weapon system. If one conceptualizes the process generally as was done in Figure 1, it can be seen that the design process is viewed as making decisions based on the available technology to meet the objectives established. The objective may be singular or multiple so that the design process is restrained by existing or emerging technology and the pre-established design objectives. We are hypothesizing that the availability of a technological innovation would affect the design process. If the innovation is implemented in the design, the result will be a different weapon system design. Each weapon system design may have different human resource requirements.

The simplified diagram presented in Figure 1 illustrates the basic considerations being addressed. Naturally, an innovation may be rejected as having no impact on design. Or the selection of the innovation may have such a small impact on the design process that no significant difference would be reflected in the weapon system produced. It would also be possible to have two weapon system designs which would have the same human resource requirements. (Note: in this paper, the human resource includes not only the operator of the weapon system but also the support staff which maintains the total man-machine system.)

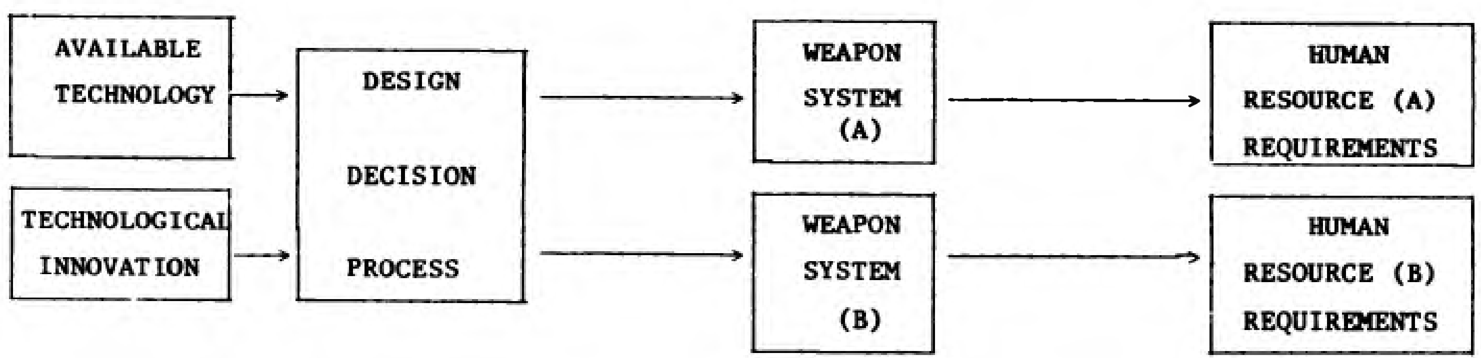

Figure 1. Technological Innovation Impact on Human Resource Requirements

The final goal would be the establishment of a technique which would allow a quantifiable description of an innovation which provides the capability of predicting human resource requirements. This action would effectively prelude the detailed design process and weapon system outcome stages and establish the link between technological innovation and human resource parameters.

The present research effort is a multiphased program directed toward the generation of methods for identifying and measuring, prior to system development, the effects of technological innovation on the human resource parameters required to maintain and operate a weapon system which will incorporate the technological innovations into its design. The ideal objective of this effort is to generate this data in forms useful to system designers and personnel planners to be considered in design decisions and manpower requirement projections (see Appendix A-1).

Presented in the following pages are the results of the first phase of the effort, a search and critical analysis of the literature reviewing the current status of forecasting and assessing technology and in the techniques for predicting the impact of technology on human resource parameters. This survey is not an exhaustive review of the literature in the area of technological forecasting and technology assessment. It was felt that the objectives of the study would be better served by the inclusion of selected references which discussed the current methodologies in detail and which were judged to be representative of the field. For a more comprehensive grasp of this field, the reader is referred to Martino (1972), Ayres (1969), or Cetron (1969). In addition to the material contained in these references, a reader interested in a more extensive consideration of technological forecasting is referred to the bibliographies provided by Harrison (1971), 800 references, and to Chamberlain (1971), 108 references.

A total of 140 documents applicable to this effort were reviewed. Of these documents, 17 were identified as being of major importance to the present effort. Expanded summaries were made of these key documents. These summaries are included as an appendix.

Emphasis of this survey was directed toward identification of methods for assessment of the impact on human resource parameters of advances in

technology. Many of the usable and relevant documents described efforts performed by or for the various branches of the military. Air Force sponsored studies predominated, a finding comparable to an earlier review of the literature on prediction of personnel requirements (Folley, Fairman and Jones, 1960).

In addition to a conventional search of the professional literature, the principal sources for document identification were the computer-based reference systems of the Defense Documentation Center (DDC), National Technical Information Service (NTIS), the System Development Corporation INFORM and ERIC/ORBIT, and the Ohio State University computer-search systems.

Section II

FINDINGS

METHODOLOGIES FOR PREDICTING AND ASSESSING TECHNOLOGY

Summarization of the diversity of methods for predicting a future state of technology appears best accomplished by classifying the many techniques under generic headings. The current body of information available concerning technological forecasts and assessments reflects the merging of ideas from several formal disciplines. It is also apparent in reviewing the area that the objective of an assessment or forecast, which is always to predict the future, may vary in the sense of how the projected inforamtion is in itself used. The general concept of what is regarded as technology must also be considered. The transfer of scientific knowledge into a technology or the adaption of an existing technology to a new use are two distinct processes which should be addressed. In the first instance the concern is with vertical transfer; in the second, horizontal transfer (Rooney, 1971). Whatever the concern, the impact of technological change must be evaluated in the context of the outcome objective. The objective may be to establish the feasibility of some innovation or to resolve a decision problem. Due to the multi-disciplined development of this area an unwieldy conglomerate of methodologies has emerged which are used to project the future. As Lanford (1972) points out:

> The consideration of the subject of technological forecasting has been made more difficult by the differing terminologies that applied to the same or to similar methodologies, by the proliferation of 'methodologies,' and by the discussions of 'intuitive,' 'exploratory,' or 'normative' techniques. Further problems have appeared in considering techniques of resource allocation as forecasting methods.

In attempting to address this problem, some taxonomic structure is required. Perhaps the most parsimonious attack would be to build upon the assumptions of a technological forecast.

Since direct knowledge of future events is unknown, there would appear to be two primary assumptions underlying a forecasting methodology. First, data or information about past events can be obtained and quantified, and second,

there is some relationship between past and future events. The difference in methodological approaches therefore, largely hinges upon the type of relationship assumed between past and future events.

A popular initial taxonomy includes three major methodological approaches: intuitive, exploratory, and normative. The current state of the discipline indicates that these categories are not satisfactory. Several authors have pointed out that all approaches can be considered intuitive (Martino, 1972, Lanford, 1972a). The term intuitive therefore loses its function when considered in the broader philosophical sense. The approach normally labeled exploratory also has lost much of its value since so many approaches fall under this category. Therefore, a new taxonomy seems to be appropriate. It is suggested that there are basically two major approaches, that of projecting the future from available data (extrapolation), and that of establishing a set of desired goals in the future and working back to the present situation to determine the changes necessary to obtain the goals (normative).

In addition to these major approaches, it is beneficial to consider the technique for gaining the basic data used in the projections. There appears to be three basic techniques employed in the extrapolation approach; judgmental, projection and analogy. In the judgmental technique, the expert opinion of individuals is collected in some fashion to establish a quantifiable value. In the projection technique, some relatively empirical measure is collected, and then a curve is selected to project future expected data points. In the analogy technique, some associated variable is linked to the variable of interest and its patterned relationship is used to determine the outcome.

The normative approach appears to consist of two basic methodologies; network construction and matrix consideration. In the network construction approach, points of critical concern are identified projecting backwards from desired goals to the current situation. In matrix consideration, several vectors of interest are generated and a matrix of interactions is developed to establish a quantifiable value of each interaction outcome. Figure 2 displays the taxonomy with some specific methodologies displayed. [For a more comprehensive presentation of methodologies, see Lanford (1972a), who has collected all the methodologies together for review.]

Judgmental Forecasting

Although this paper considers the judgmental technique as an extrapolation method, it is usually considered exploratory. The classification is made on

	EXTRAPOLATION		NORMATIVE	
JUDGMENTAL	POLLS PANELS DELPHI	NETWORK CONSTRUCTION	MORPHOLOGICAL DECISION TREES FUNCTIONAL ARRAY	
PROJECTION	REGRESSION BIOLOGICAL GROWTH ECONOMIC GROWTH			
ANALOGY	CORRELATION CURVILINEAR CORRELATION	MATRIX CONSIDERATION	CROSS IMPACT MISSION NETWORK SYSTEMS ANALYSIS	

Figure 2. Technological Forecasting Taxonomy

the basis that these procedures are concerned with exploring the possible futures inherent in present capabilities. Though all methods discussed up to this point are exploratory, the term "exploratory forecasting" in recent popular usage appears to be frequently associated with the Delphi procedure.

Since its reported genesis in 1963 (Dalkey and Helmer), the Delphi procedure has been extensively used by those engaged in exploratory forecasting exercises. This popularity may be based on the fact that the Delphi approach is designed to arrive at a prediction of what the future situation will be, rather than a consideration of the many possible situations that could exist in the future.

A second basis for appeal of the Delphi procedure may lie in its demonstrated reliability. Reliability here is used in the experimental sense; comparable results can be produced by repetition of the procedure with different panels (Ayres, 1969).

The Delphi procedure has characteristics which serve to differentiate it from other tools of the forecaster. It maintains anonymity of the participant experts throughout the complete cycle, thus obtaining the advantages possible from group interaction and at the same time obviating the disadvantages inherent in such an approach: the effects of vested interests, common biases, disproportionate influence of a dominant individual, and pressure to agree with the majority view (Gordon and Helmer, 1964).

The Delphi procedure, however, should not be viewed as the complete panacea to the forecasters' dilemma; for, as cautioned by Martino (1972), "Although the Delphi method . . . is both popular and practical, it suffers from the shortcoming that it is almost completely subjective in nature." A further criticism of the Delphi procedure is that it concentrates on one event at a time and thus does not allow a consideration of interactions among the events being forecasted. Reacting to this criticism, a procedure was devised by Helmer and Gordon, termed "Cross Impact Analysis," which can be used to arrive at an analysis of the interactions among events forecast by a Delphi panel or, for that matter, from any other source of forecast.

Lanford (1972b) discusses the impact study approach and relates it to the system analysis approach. Blackman (1973) compares a cross impact model against a decision tree approach for long-range planning and asserts that the cross impact analysis has greater utility in that it reduces the complexity of the forecasting task.

Projection Forecasts

In this method of forecasting, the forecaster systematically records the past rate of technological innovation and advance in the area of interest, assumes this past rate will continue into the future and fits an appropriate trend to the data, generally through the use of a regression technique. An example of application of this procedure can be found in Lamar (1969). This method of forecasting is subject to the same caveats that are expressed for statistical applications of regression analysis; for example see Ostle (1963).

A more complex approach is to select a curve fitting technique employed in other areas of research. This approach to forecasting has made use of systematic procedures developed by biologists to explain and predict the process of biological growth. The basis for this adoption lies in an observed parallelism between biological growth and "growth" in performance of technological devices. The biological growth curves have been used as conceptual models for technological development with the goal of obtaining greater accuracy of prediction. Lenz (1962) described this approach, but did not lend strong support to it. Biological growth curves based on mathematical functions have also been investigated by forecasters. Two growth curves frequently used in technological forecasting, the Pearl-Reed curve and the Gompertz curve, are discussed by Martino (1972). Martino contends that neither method can be viewed as being completely rigorous. However, he does conclude that the use of growth curves is preferable to the Delphi method if sufficient historical data are present.

Analogy Forecast

Analogy forecasting is an attempt to arrive at a forecast by comparing the present situation with some similar technology in the past. A more

precise attempt in this area would be the establishment of a relationship with another innovation or variable which can be measured or quantified so that if the relationship is known, a projection can be made based on the analogous indicator. An example would be the work of Mazlish (1965) who used the development pattern of railroads as an analogous indicator for the space program in exploring the process of projection by historical analogy. A number of problems are associated with this technique. One of the major problems is referred to as the error of "causal analogy" (O'Conner, 1970). This error is committed when one observes a few similarities between the past technology and the situation he is seeking to forecast and, without gathering more evidence, concludes that the two situations are in fact analogous. More involved problems in forecasting by analogy include the introduction of possible forecaster bias in his refusing to consider "implausible" outcomes. An associated problem is that of historical uniqueness. In this problem area, the forecaster is drawn into an erroneous conclusion, since his historical base is not representative of the past situation. These sources of error, as well as others, are discussed in more detail in Mazlish (1965).

Network Construction

The techniques of forecasting grouped under the descriptor "network construction" are, to a large extent, products of systems analysis procedures and emphasize the use of some quantitative approach. Cetron, Martino and Roepcke (1967) report on 30 quantitative methods applicable to research and development decisions. Normative methods attempt to identify and to locate, with reference to one and another, the elements of some system and to investigate relationships existing between the elements within the system. These techniques are amenable to, and are frequently used for, examination of system limitations, capabilities, costs, and design optimizations for identifying an approach leading to best attainment of a special goal. Three basic techniques of network construction forecasting which are the most typically used in forecasting exercises are: relevance trees, mission-flow diagrams, and morphological models.

Morphological models are used in the unique circumstance where no hierarchical relationships exist between the elements being considered and where each element can be altered without ensuing system ramifications (Zwicky, 1969).

The use of mission-flow diagrams is most practical for system description. The system is described in terms of branching paths where the description can be accomplished by use of one or more series of segmented steps or paths. This technique was originated to permit the analysis of the elements of selected military missions. Probability of accomplishment or cost, as examples, can be associated with each step along the flow diagram, and the diagram can then be used to generate a normative forecast for another variable such as performance requirements to satisfy the mission.

The relevance tree approach is typically used in a circumstance where specific levels of abstraction, or complexity, can be identified. Historically, the relevance tree method was commonly used for organized description purposes and had wide biological and botanical application. The initial application of a relevance tree approach to forecasting was apparently performed by Wells in 1958 (Cetron, 1969).

A full-scale application of the relevance tree method was performed by Esch for the Honeywell Corporation. Continuing development by Esch and Jestice resulted in a procedure called "Planning Assistance Through Technical Evaluation of Relevance Numbers (PATTERN)" (Esch, 1965). In this approach "relevance" numbers are assigned to the options at each level of the tree. A path is selected through the tree and the product of the numbers on each branch of the path followed is obtained. This product is used as a figure of merit for comparison of this path against other possible paths in the tree. At each level in the tree, the relevance numbers assigned are proportions which satisfy a restriction that the total for the level must sum to unity. This process is referred to as "normalization" of the relevance numbers and is a distinguishing feature of the PATTERN approach and, in general, of the application of relevance numbers in relevance trees. A danger in following this technique lies in placing too much confidence in the significance of differences between the numbers obtained through such a procedure (Martino, 1972) (see Appendix A-2). As an example, it can be established quickly that the figure of merit for any specific approach in a simple tree having only two levels would be expressed to a hundredth. The decision with respect to the absolute size of a difference which will be accepted as significant therefore must be approached with caution.

Overview

Despite the plethora of proponents and techniques available for technological forecasting, the majority view of those who have tried to assess this discipline seems to be something less than optimistic. Dory and Lord (1970) in an article asking the question, "Does Technological Forecasting Really Work?", concluded that, "Technological forecasting, the perception and interpretation of change, appears to represent a far more difficult problem than is currently indicated by its proponents or addressed by their techniques." Another criticism was voiced by Bright (1970), "It (technological forecasting) remains inadequate for some of management's needs because: (a) ... ; (b) forecasts of technical capabilities do not necessarily deal with their diffusion, input requirements, and impact."

In a broader context, an Interagency Task Group on Technological Forecasting in the Federal Government (1966) concluded, "There is little, if any, evidence of successful attempts to forecast actual 5 to 10 year requirements for skill in broad classes of occupations." In this same time frame, Hacke (1967) (see Appendix A-3), discussing the feasibility of anticipating economic and social consequences of technological innovation, talked about two aspects of forecasting, parameters and patterns. According to this author, the forecasting of parameters has been the subject of much work. As Hacke states, "The following examples demonstrate that there is no lack of methods for forecasting trends in socio-economic parameters:...." Hacke continues, "In the projection of economic and social patterns, by contrast, little has been done that goes beyond historical analogy and expert opinion." Earlier Schoeffler (1955) was more critical in his evaluation of explanations of changes in patterns by categorizing them as "story telling." Though this statement was made almost 20 years ago, the situation apparently has not been completely reversed.

A summarization of the criticism of technological forecasting methods was succinctly made by Lenz (1969) in the following quotes,

> In practice it may often be observed that data for parameters of performance which would be useful for measurement and prediction of progress are very

> difficult to obtain. Performance is sometimes not measured at all, or is often not measured at regular intervals . . . ..Thus without a clear and specific knowledge of exact limits of present and past performance, it is not unusual to find a reluctance toward projecting or publishing forecasts of future performance in the same area.

Lenz continues, "The development of a useful quantitative forecast, using even the simplest methods of trend forecasting, is likely to become a lengthy research project." Lenz summarizes the products of technological forecasting by stating, "The scarcity of good examples (good forecasts) is compounded by the difficluty of the search through large quantities of material labeled as forecasts of future trends to find the few which are useful." (Support for this statement may be found by consulting the bibliography compiled by Harrison (1971). The author identifies more than 800 sources pertaining to technological forecasting spanning the years 1936 to 1970.)

Roberts (1969) (see Appendix A-4), critically appraising exploratory forecasting, concluded that most of the existing methods are variants of simple trend extrapolation procedures and have limited utility in the current dynamic technological environment.

This objection to the lack of development of more than a simplistic approach method is also made by Jantsch (1967) in his statement that only a limited number of influencing factors are taken into account and mathematical formulations "do not yet include even all of these recognized factors."

Of the Delphi procedure, Roberts speculates about "whether a Delphic sampling of appropriate whiz kids would have predicted an effective intercontinental ballistic missile when Vannevar Bush failed in his prophecy!"

Roberts argues strongly for the need of a "learning model" which would combine a real-time system, on which data could be collected and interpreted, with a forecasting model. This combination could allow "parameter and possibly even structural changes in the forecasting model based on experienced model ... performance."

Normati[illegible]sting is viewed by Roberts as failing to direct a sufficient a[illegible] toward verification of the correctness of the

assumed relationships between allocated resources and generated technology. Supporting this statement is the Dory and Lord (1970) comment, "We agree with the literature that normative forecasting is a better answer than the exploratory approach for many applications. We are not sure either attacks the real need for information."

Roberts concludes his appraisal by calling for a technique integrating exploratory and normative forecasting methods and making use of feedback loops.

In retrospect three points need to be considered. First, although there are a considerable number of techniques currently being used to forecast technology, none of these are singularly more effective. As in any discipline they should be viewed as basic tools, each with its own peculiar unique advantages and disadvantages. To a degree the selection of a given technique is predetermined by the purpose of the research. In addition, a consideration must be made as to the type of information that is desired as a final outcome. Drawing upon Metroff and Turoff (1973), an adaptation of their conceptualization of information types is provided in Table 1. As can be seen, the type of consideration ranges from the relatively simple one of establishing the technical feasibility of a specific short term goal such as the use of Wankel engines in aircraft to the more complex long term goal exemplified by the reduction of population growth over the next 90 years. The selection of a specific methodology may be strongly influenced by the type of outcome information expected. For example, type IV information, such as how to geographically allocate Air Force resources to maximize Air Force effectiveness in meeting national objectives, would probably require some type of matrix consideration in the attempted forecast.

Second, the technique selected only provides a methodology not a certainty. The technique can only be asked to be effective if the data is in some way reliable, valid and credible. The strongest technique cannot withstand the vibration of inconsequential data. Therefore, a far greater effort must be plac upon data measurement and operational definitions of variables being consi Prior to this time most technological forecasting and assessment has been on either highly restrictive quantitative data; i.e., weight versus thrus engine performance, which may not reflect the conceptual variable of inter performance (Alexander and Nelson, 1973), or on extremely general observation which lack the reliability desired in measuring a variable (Simmonds, 1973).

Table 1. Types of Information Obtained in Technological Forecasts and Assessments

(Adapted From Mitroff & Turoff 1973)

TYPE	DESCRIPTION
I Feasible Technological Developments	Feasible usually means, in this context, technically feasible if the "required" resources are invested or available.
II Potential Applications	This is any possible application of the previous technological developments without regard necessarily to values - i.e., whether the application is good or bad.
III Significant Applications	This is some subset of "all" potential applications or a transformation to some set of significance to the intent of the study.
IV Potential Consequences	Any consequences, good or bad, which may affect opinions of scenarios about the future, or our interpretation of the past.
V Policy or Resource Allocation Issues	Concerned with the decision issues under examination or arising as a result of potential consequences of decisions.
VI Potential Resolution of Issues	The controls that can be imposed to effect the likelihood of various developments, applications, and consequences.

Third, what we are attempting to forecast is in itself not generally defined. That is, technology is an extremely broadly interpreted word which can be anything from a broad scientific discovery, such as fusion, to a highly specific item, jet engines. In either case the research scientist is interested in determining the impact of some perhaps almost unknown event in terms of a very concrete system or outcome. The very fact that someone may be concerned with the impact of the laser upon photography does not in itself establish any given approach. The technological innovation must be defined in some specific set of characteristics which in turn must be related to the photographic characteristics of interest. The vast latitude between the specificity of forecasts creates one of the major hazards in any logical synthesis of available research. This, perhaps, suggests that in order to study the question, a series of interrelated studies may be necessary to establish a conceptual network of data which will be the result of several different approaches to the problem.

METHODS FOR RELATING STATES OF TECHNOLOGY TO THE IMPACT ON HUMAN RESOURCES

Qualitative and Quantitative Personnel Requirements Information

Through a process of evolution, the Air Force developed a concept for stating personnel and manning requirements of developing systems. This concept has undergone a series of modifications and name changes; it is currently known as Qualitative and Quantitative Personnel Requirements Information (QQPRI) (USAF, 1961). The QQPRI is a statement of projected manpower required to operate and to maintain a new weapon system. It is usually based on a task analysis and is summarized in terms of an "average" operational unit. The summary lists the numbers and career areas of personnel required. It also provides an indication of the skill level of each individual. Folley, Fairman and Jones (1960) conducted a survey of the literature on methods for prediction of Air Force personnel requirements. The overwhelming majority of the 121 documents abstracted dealt with QQPRI and its antecedents. Only 1 of the 121 reports surveyed addressed the question of elaboration of a procedure for estimating manpower requirements (Ray et al, 1957). This procedure used a rating scheme developed by Ghiselli and Brown (1955) which classified skills into 3 levels of complexity. The approach was based on use of the same inputs involved in QQPRI generation and appeared to result in the same product, specification of QQPRI data. Thus, the Ray procedure presented no basic improvement

over the QQPRI method. The reader interested in more detail concerning QQPRI is referred to Losee et al (1961) and a later effort, Demaree et al (1962), which detailed the approach methodologies used to produce QQPRI and made distinctions between QQPRI and other products in the Personnel Subsystem effort. Both documents were intended to serve as guides to the preparation of QQPRI for use in weapon system development efforts.

A look at extra Air Force attempts to establish procedures for specifying personnel and training requirements for incoming weapons systems is provided by Rupe (1963). Haines and Gael (1963) (see Appendix A-5) conducted a survey of manning estimation techniques used in defense industries. In all cases surveyed, QQPRI was used as the approach method. The resultant QQPRI products were found to be based on five methods of obtaining input data. These were: expert estimate, historical comparison, task analysis, "sovereign factors" (e.g., cost used as an index of complexity together with a queuing theory approach), and modeling approaches. Essentially, the QQPRI concept has not changed since these early reviews.

The search for a method to specify system manning requirements earlier in the development cycle of the system has led to investigation and experimental application of simulation techniques with AFM 66-1 (1972) type maintenance data along with other inputs as the information base. These procedures to date are not documented in published material.†

Simulation Techniques

The feasibility of specifying manning requirements of advanced systems by means of mathematical modeling approaches has been investigated for at least a decade. Barton et al (1964) (see Appendix A-6) used two mathematical techniques (queuing and a linear programming model) to compute manning requirements and training needs in a developing system. The authors pointed out that, "in practice, failed systems or units pile up in lines waiting for service or men are incompletely utilized." They felt this model adequately dealt with these conditions. A set of queuing tables for use with this model was generated by Purvis, McLaughlin and Mallory (1964). Further

† Personal communication with R.J. Schiffler, (USAF,ASD). The interested reader is referred to AFHRL prepublication draft: York, Michael L. (Major, USAF), A-10 Manpower Requirements Development Test, 14 September 1973.

investigation of this application of queuing techniques was made by Purvis, Mallory and McLaughlin (1965) (see Appendix A-7) with the intent of establishing the validity and reliability of the procedure for predicting manning requirements for weapons systems. The approach used by the authors was the application of the procedure to an operational system (the F-105D fire control system) and to a system in development (the C-141). The conclusion reached was that the approach was usable and that "the technique clearly establishes the validity of the finite cyclical queuing process as an accurate description of the F-105 fire control system ...."

Snyder and Askren (1968) (see Appendix A-8) support the statements of Purvis, Mallory and McLaughlin with their conclusion, "queuing techniques are valid and reliable for predicting requirements and making trade-offs between manning and personnel skills ...."

Approaches taken by other investigators to simulation model solutions for specifying the impact of technological innovations on human resource parameters have included Bradley (1968) and Floyd (1968). Bradley suggested a Monte Carlo simulation model emphasizing prediction of manpower and spares requirements. This model was computer based, but provisions were made for manual application. A different modeling approach was advanced by Floyd, who suggested a mathematical model leading to the development of trend curves for prediction when two conditions were satisfied; first, an ultimate limit could be identified and, second, when at least two data points were available. Current efforts under Air Force direction include the experimental effort mentioned in the section above, which is an approach entailing mathematical modeling of future aircraft systems' human resources requirements based on AFM 66-1 maintenance data assembled on a current comparable-mission aircraft. This effort resulted in the development of a computerized model which considers operations scenarios and task data to project resource levels of men, spares and aerospace ground equipment (AGE). The research has been completed and a series of reports are being drafted. The technique has been adapted for some current Air Force systems.

Statistical Approaches

Closely related to modeling techniques are statistical approaches to the prediction of the impact of technological innovation on human resources. The

statistical approaches to this problem have, to a large extent, emphasized regression analysis procedures to arrive at an estimate of the effects of equipment design characteristics on skill requirements or job performance.

Meister, Finley and Thompson (1971) used a multiple regression analysis as one of the steps in a process which they termed "a sort of 'poor man's factor analysis'." For a summary of the procedure advanced by these authors, refer to the expanded summary included in Appendix A-9.

The authors identified four factors as prime determinants of maintenance performance. These were accessibility, amount of diagnostic information, equipment configuration, and technician capability.

The expected recommendation for replication with an expanded sample size to increase confidence in results was made. An interesting conclusion enumerated, but not emphasized, by the authors was the suggestion that length of experience after skill level qualification was not an important design parameter. In view of the potential training and design consideration impacts represented by such a condition, any replication of this study should direct specific attention to collection of data addressing this issue.

Smith, Blanchard and Westland (1971), investigated subjective techniques for generating human performance repair time data required for predictions of maintainability of proposed equipment. Data generated was compared against AFM 66-1 maintenance data by means of regression analysis techniques. The relationship was found to be linear ($y = 1.2756x + 0.7021$) with a positive correlation of 0.86. The authors concluded that subjective judgment could be used to predict maintainability of future systems.

The relationship between equipment design characteristics, training costs and difficulty, and job performance was investigated by Lintz, Loy, Hopper and Potempa (1973) (see Appendix A-10). The approach was through the use of a principal components (stepwise regression) analysis to derive prediction equations for performance time, errors, training time, and training equipment cost. Variables correlating significantly with performance were subjected to a factor analysis. This procedure resulted in the identification of six factors. The authors concluded that the procedures followed provided a quantitative method for predicting the variables under study and that such

predictions could be used as considerations in a system design process. The authors call for validation of the procedure through following a system design effort from conceptualization to operational use.

A subsequent study employing the same methodology was conducted by Lintz, Loy, Brock, and Potempa (1973) (see Appendix A-11). Organizational and intermediate level maintenance data were collected on 10 avionics subsystems. Within these subsystems, selected equipment design characteristics were either measured or subjectively rated. In addition, 16 personnel variables were used. Maintenance tasks of differing levels of difficulty were used for estimating performance times and error probabilities for both high and low skill level personnel.

Design, personnel, performance, anddifficulty variables were intercorrelated and were entered into regression and factor analyses. Equations were derived for predicting maintenance task difficulty and maintenance performance times. Maintenance performance time was predicted through a consideration of personnel and task difficulty variables.

Multiple correlation coefficients (Rs) for predicting times from design characteristics ranged from 0.87 to 0.93. Task difficulty coefficients ranged from 0.73 to 0.80. Factor analyses on performance, personnel and design variables yielded some 17 factors over the different maintenance levels studied. The authors concluded that the results supported the merit of such an approach to predicting maintenance performance times and task difficulty and felt an extension of the procedure to additional avionics equipment was in order.

A factor analysis approach was also used earlier by Topmiller (1964) as an approach method for conducting human engineering analyses and predicting system maintainability. A more global approach was employed in that the author was primarily concerned with equipment classes rather than directing attention to the LRU level - the object of study in Lintz, Loy, Brock and Potempa (1973). Topmiller reported that increased predictive efficiency was experienced with his approach when equipment was classified into homogeneous sets.

Gross Projection Methods

Most frequently encountered in reviewing the literature are studies of the effects of technological change on skill level where skill level is treated only in terms of gross projections.

Crossman (1960) provided a scheme for study of types of automation which involved classifying the types into continuous flow production, programmed machine, and centralized remote control activities. One of the impacts of automation, according to Crossman, would be the developing requirement for a multiskilled maintenance man, a skill type he alluded to as a "polyvalent craftsman." Davis (1962) concluded that levels required for semiskilled mass production jobs would be suitable for operators of automated equipment. Beaumont and Helfgott (1964) reporting on a study of 36 companies concluded that worker skill requirements were fundamentally unchanged by technological innovation. Bright (1966) arrived at the disparate conclusion that automated machinery tended to require less operator skill. Crossman and Laner (1969) (see Appendix A-12) separated skills into direct and indirect labor and reported finding an increase in direct labor skill requirements but concluded that with the inclusion of indirect labor into the consideration there was no overall increase in mean skill levels required as a result of technological change.

Kraft (1970) called for study of specific skill responses required at various stages of automation. He felt that such an approach might provide the information needed for adequate manpower planning.

Relevance Tree Approaches

The earlier referenced efforts of Wells (1958) apparently represented the first application of a relevance tree approach to the problem of the technological forecasting for impact considerations. Continued attention was given to this procedure by Esch and Jestice (Esch, 1965) with the result that "relevance numbers" were attached to the branches of the tree to permit selection of an optimized path through the tree.

Hwang (1970) was one of the early investigators to perceive the relevance tree approach as a vehicle for study of specific weapon system prediction questions. Hwang attempted to establish the comparability of risk analysis

to a systems analysis approach. He used a decision tree approach in consort with methods of risk analysis to predict risk in materials acquisition for the U.S. Army.

In contradiction to a conclusion reached by Meister and Farr (1967), Lintz, Askren, and Lott (1971) reported that design engineers did consider human resources data if it was available and that when considered, this data did affect resulting designs. The authors recommended that human resources data be included as one of the design parameters in weapon system development. In seeking an answer to the problem of quantitative specification of human resources impact data in advance of the actual application of a technology, one of the above authors, Askren, in collaboration with Korkan (1971) (see Appendix A-13) investigated the feasibility of the use of a relevance tree approach as a vehicle for relating human resources data to design decision alternatives. The relevance tree developed by the authors reflected weapon system decision options and was termed a "Design Option Decision Tree (DODT)."

The underlying basis for the development of this particular research approach apparently lies in the fact that in the design of a weapon system, the system designer can rely on a store of past engineering data which can be considered in selecting the hardware design option to follow. However, as these authors succinctly indicate,

> In the case of human resources data, there is no such bank of historical data. Thus, the need exists for the generation of data descriptive of Air Force human resources implications of the various design options identified in the decision trees. The generation of these data likely will require a combination of efforts, such as collection of historical and field data, and the generation of data through simulation and psychophysical procedures.

The authors concluded that design option decision trees appeared to provide a vehicle for permitting a systematic consideration of human resources factors involved in a specific design decision.

In a follow-on study, Askren, Korkan and Watts (1973) (see Appendix A-14) investigated the feasibility of measuring the sensitivity of human resource parameters data to design trade-off problems reflected in a DODT. Eight

trade-off problems were chosen from an aircraft propulsion tree and psychometric data collected concerning the effect of these design options on selected human resources topics. The authors concluded that the study demonstrated the feasibility of the use of psychometric methods in conjunction with a DODT to develop selected human resources data for use in system design decisions.

Other Approaches

The attempts to relate the effects of technological innovation on human resource variables over the rec. ': past appear to have emphasized rather restricted avenues of investigation. The approaches represented by QQPRI generation, regression analysis, queuing and relevance tree techniques dominate the relatively sparce literature in this area. Isolated investigations of the feasibility of application of other approaches are found, but generally are not the subject of more than one investigation. Thus, in 1961, Thomas et al (see Appendix A-15) described a method they had developed for generating data on the effects of various levels of automation on human performance in a man-machine system. The method was advanced as a meaas of studying system control problems anticipated in the design of an advanced system.

Crossman (1965a) reported on an approach intended to define skill level on a scale independent of the content of the skill. The approach suggested entailed measuring the man-hours expended in developing the skill resulting in a scale which would be "divisible into some six or seven levels." The Crossman scale basically would represent a parallel system to the Air Force scheme of skill levels and would be developed on a less satisfactory data base.

In 1969 (Meister et al), an investigation was conducted concerning the design engineer's concept of the relationship between design characteristics and technician skill level. The authors asked their sample of design engineers to rank ten statements of "different levels of maintenance skill" along a ten-point scale. They concluded, "Engineers claim to be capable of differentiating ten levels of personnel skill."

Dean (1959) in an unpublished dissertation, reported on an investigation of the "primary intellectual, perceptual, visual, interpersonal, procedural

and muscular skill requirements" imposed by the introduction of automated equipment in seven case studies of industry. A Job Description Check List, developed by Storey (1958), was used to provide quantitative indices of the skill components listed above for each case studied, both before and after automating. Dean found no effects of automation in 75 per cent of the observations. In the remainder of the observations, the number of skill increases were approximately equal to the number of decreases.

Schulze (1971) reported on an attempt to relate equipment design features to selected psychophysical indices. Though finding no statistically significant differences, the author reported strong trends for a majority of the indices to be higher during the more difficult tasks.

From the information available it appears that the relationship between existing states of weapon systems and human resource parameters has only been addressed in a crude and unsystematic manner. The prognostic needs of the armed services forged the concept of QQPRI, but this concept has lacked a specialized technique which would provide adequate information. Some of the methods used establish acceptable projections of manpower but are usually applied after the weapon system has transitioned into the production phase. Initial efforts have shown that human resource parameters will affect weapon system design if the impact of a given trade-off has reliable data provided.

There is presently no body of information that would provide the required relationships between design characteristics and human resource parameters. The design option decision tree technique provides a network instruction technique that allows us to reduce a system problem into a series of functional decision points. This certainly provides insight into complex system problems, but it does not establish the necessary relationships. It is concluded that the methodology currently available in the area of predicting human resource requirements for a given system is not any more advanced than forecasting methodology, and it deals almost exclusively with the three manpower considerations of quantity, job type and skill level.

Overview

Research attempting to relate the impact of technological innovations on human resources has, to a large extent, emphasized the investigation of the effect of automation on overall manpower skill requirements. The more com-

plex issue of anticipating the specific changes which application of a technological advance generates within a particular skill classification has been neither adequately treated nor resolved.

An extensive review of earlier efforts directed toward assessment of the impact of automation on manpower skill requirements was conducted by the International Labour Office (1965). This effort reviewed 160 studies, 49 of which were accomplished in the United States. Each of the studies was categorized in terms of the kinds of technological change involved and was classified with respect to its effect on selected social, economic, occupational, and personal factors. The studies in this review, and many of the more recent studies, have dealt with skill requirements in terms of gross census-type predictions.

In criticism of earlier work in this area Crossman (1965b) concluded, "To this date, we have essentially no valid models which will predict the rate of progress of automation in any single case, nor the likely changes in skill input."

That attention is still directed at the level of gross projection is reflected in sources such as Buechner (1972) (see Appendix A-16), who concluded that technological change and associated automation served to reduce demands on labor, but cautioned that the nature of his data did not allow consideration of individual jobs.

DeGreene (1974?) asserts that in spite of 20 years study, a categorical statement concerning the effect of automation on skill requirements cannot be made.

A major criticism leveled against QQPRI has been the relatively late stage in the system development cycle at which personnel information became available. Attempts to develop specific human resource information at earlier points in the system development cycle have led to investigations pursuing the approaches summarized in the sections above. To date, no approach has provided the answers sought. At least one individual (DeGreene, 1974?) addressing this area of concern, pessimistically concludes, "... it will probably be at least years before a predictive or even an explanatory theory of technological changes (as related to manpower resources) is developed."

DeGreene calls for development of a systems theory integrating the various approaches of psychology, engineering, computer sciences, economics, and other related fields to deal with this problem.

POTENTIAL METHODS FOR PREDICTION OF IMPACT OF TECHNOLOGICAL INNOVATIONS ON HUMAN RESOURCE PARAMETERS

Esch (1965) reported on a modification of the PATTERN relevance tree undertaken by the Honeywell Corporation in an attempt to identify present and future needs in bio-medicine. This effort was referred to as "Project Medicine." The term "medicine" in the title was an acronym standing for medical instrumentation and control identified and numerically evaluated. This procedure used the decision structuring and relevance number assignment techniques developed for PATTERN but redefined the levels within the tree. For example, in the hardware trees, the primary activity level is the task level. In the bio-medical tree, this level was concerned with such activities as diagnosis, palliative procedures, curative procedures, and prevention. System and subsystem levels of the hardware oriented tree became major body activities (e.g., blood circulation) and body organs, respectively. In this fashion, the relevance tree was employed by Honeywell to plan a research and development program in medical electronics, thus providing a demonstration of the generalizability of the relevance tree approach.

Investigating the relationship between advanced technology and work group behavior in a replication study, Taylor (1970) reported support for earlier conclusions that a pattern of greater peer leadership was more evident in groups exposed to more advanced technology and that an advanced technology climate facilitated planned social change efforts.

Bezdek and Getzel (1973), using gross projection methods, predicted the skill requirements for three future socio-economic environments: a status quo, a social-welfare, and a defense economy. They concluded that for all three futures manpower requirements at upper skill levels would be substantially increased. The choice of national priorities was viewed by the authors as exercising a significant effect on skill types within job families. This factor was viewed as a compounding problem making accurate prediction of education, vocational and skill requirements very difficult.

The application of the material in this and in many of the other articles in this area is restricted by the same problem encountered earlier; most articles address themselves to trend extrapolations and gross predictions (e.g., Gordon and Ament, 1969), thus provide little useful insight for answer to questions concerning specific impact effects on human resources. This sentiment is supported by Hacke (1967) who stated, "It is not feasible, however, to forecast quantitatively the trends in a (social or economic) parameter or pattern with the certainty that the outcome will fall within the stated confidence limits ...."

QUANTIFICATION OF HUMAN PERFORMANCE FACTORS IN SYSTEM DEVELOPMENT

Isolated investigations of the problem of quantification of human performance in developing weapon systems surfaced as a result of the review of the literature. Certain of these may have application to the present effort and are identified for consideration.

A detailed examination of this topic was undertaken by a 1964 symposium on quantification of human performance. The December 1964 Human Factors Journal, a special issue, was devoted to selected (and edited) papers presented at the symposium and workshop held at Albuquerque, New Mexico, in August 1964. This issue contains a theoretical article by Leuba (1964) dealing with human parameter quantification methods. In this paper, Leuba provided examples of the types of quantifications required in man-machine systems. Leuba associated selected equipment design procedures (e.g. task analyses, trade-off studies) with the different types of measurement scales. As example; he stated, "Trade-offs imply the existence of ratio scales. This fact accounts for the current difficulty engineering psychology is experiencing in performing reasonable trade-off operations with ... systems engineers". Leuba then progressed to a summary discussion of methods of quantification which could be applied to man-machine system problems.

Unfortunately, neither Leuba, nor any of the other symposium participants could suggest a procedural solution to quantification of human performance factors in system development. Ten years later, a suitable methodology for providing answers is still needed. As DeGreene (1974?) states "To date there has been no cohesive examination of the interrelationship between new

technology and manpower resources. ...abilities and skills must be better related to tasks, jobs, and occupations. This is the ongoing challenge to human factors."

In this last decade, a number of approaches to the problem of quantifying human performance factors have been attempted. Rook (1964) reported on a method for evaluating system failure performance based on rank-order data.

Irwin, Levitz and Freed (1964) reported on the application of a subjective method of obtaining human reliability data. The approach involved the use of a Likert-type scale to obtain reliability estimates for 60 maintenance tasks. In this approach, the authors related their findings to performance measures for operation of electronic equipment which were developed by American Institutes for Research (Payne et al, 1962).

Kaplan (1967) reported on the results of investigating several types of scales for obtaining value judgments from subject matter experts. Ratio, difference, direct, and paired comparison techniques were selected for study. The author selected the difference scale based on the fact that it had a standard which served to stabilize the scale in the absence of a known dimension for the measure being considered.

Finley et al (1970) performed a technical review of human performance prediction in man-machine systems. As a part of this effort, "over 500" performance prediction tests were reviewed. The authors felt that development of a usable human performance prediction technique dictated adherence to certain essential theoretical and methodolical requirements which they identified as:

1. Accomplishment of a more exact understanding and description of system and behaviorial phenomena.
2. Recognition that the prediction problems are multi-dimensional and multi-level.
3. Utilization of modern test development techniques (e.g. utility analysis.)

The final conclusion reached by the authors echoed the general concensus found in earlier research, "Human performance prediction tests can serve a great potential future role in the understanding, prediction, and control of human performance in man-machine systems; but only to the degree that many current theoretical and methodological problems are resolved."

Section III

SUMMARY

This review of literature addressed the topics of technological forecasting methods and techniques for assessing the effect of technological advances on human resources. The guiding philosophy was to identify techniques and measures which could be applied in seeking resolution to the problem of specification, in advance of weapon system development, of the effects of technological innovations on the human resources required to maintain and operate the weapon system, and of producing this data in forms useful to system designers and to personnel planners.

In order to provide this substantive analysis, a set of evaluative criteria was generated against which the identified studies were judged. These criteria were:

1. Does the method have application to the present research problem?
2. Is the method applicable in total, or are only selected elements appropriate?
3. Does the method produce results couched in quantitative terms?
4. What limitations are imposed by the method when considering such variables as
   -- cost
   -- time
   -- ease of application
   -- computer feasibility?
5. Are there any evaluative criteria associated with the proposed method; for example, can statements be made concerning
   -- probability of success with method
   -- levels (and limits) of confidence
   -- validity of the procedure?

The review of the literature failed to reveal a procedure which could be applied *in toto* to produce the answers sought under this research project. However, the review of the methods and techniques subsumed under the topic "Technological Forecasting" did suggest possible approaches having merit for the present task.

Technological forecasting is a young and vibrantly active field attracting participants from many professional disciplines. The sheer

number of practitioners and their resultant documentation compound the task of objective evaluation of the merits of the proffered approaches. However, among those attempting to appraise technological forecasting, a consensus was apparent favoring a normative approach to forecasting. This approach was felt to permit the reduction of an objective to a series of smaller choice considerations which were more responsive to some form of quantification.

Review of the available normative techniques to technological forecasting led to the conclusion that a technique amenable for study of the problem under investigation is a modification of the relevance tree method known as a Design Option Decision Tree. The relevance tree approach has been demonstrated to be a useful vehicle for carrying out successive identification of increasingly finer components. A basic strength of this method lies in the fact that it forces an organization and structuring of the problem and helps to assure a complete consideration of alternative methods for solution of the topic under study. With the design option decision tree, any number of solutions to the overall problem can be traced and evaluated in terms of their requirements on the resources and technologies required for implementation. Lastly, the use of this method provides an easy means of determining if a specific solution has been overlooked.

The design option decision tree procedure must have some method associated with it for quantitatively assessing the impact of the technologies reflected at various points in the tree on the human resource parameters which would be involved with each decision option.

Since no solution to the requirement, quantizing the impact of technological innovations on human resource parameters, was revealed as a result of the literature search, it is felt that while the DODT will provide considerable insight into the system problem, some other methodology must be used in association with it to provide the data required. The few studies located ancillary to this topic investigated selected psychometric techniques but offered no procedural solutions. The selection, or development, of a method to quantize human resource impact predictions must be an emphasized goal of the present study.

Attempts to provide assurance of the utility and validity of any technique developed in this study must be included as a part of the overall study.

As suggested by Roberts (1969), and in part employed in an earlier study (Purvis, Mallory and McLaughlin, 1965), an inherently attractive approach to estimate the validity of any proposed technique would appear to be the combination of an experential model and a forecasting model into an overall procedure termed a learning model by Roberts but perhaps more accurately referred to as an "Adaptive Model." In brief, this model would combine a real-time system, on which human resources data would be collected and interpreted, with a forecasting model. Human resources data for the real-time system also would be generated by the forecasting model. Comparison of the two data sets would permit modification of the forecasting model until a parallelism of data was achieved. At this point the forecasting model could be employed with specific areas of technological advance.

Another approach synthesized from the literature review might be classified as an "Incremental Approximation" method. This approach is suggested by the procedure followed in studies reported by Crossman and cohorts (1966 and 1969) (see Appendix A-12 and A-17). The procedure basically would represent a refinement to the adaptive model proposed in the last paragraph.

This approach is conceptualized as entailing the selection of a technology area which has experienced recent application of some technological innovation. The area selected must have available instances of both the static and the innovative technology in operation. Empirical data is collected on the operation employing static technology. The normative predictive procedure and quantification method is independently applied to this same technology and refined as described under the adaptive model. The revised prediction procedure is then applied against the operation incorporating the innovative technology and the results validated against empirical data collected from field operational experience with the innovative technology. After making any indicated refinements, the prediction procedure is then ready for application to conceptual systems employing anticipated technology.

Reiterated, the overall research goal of this study is the development of a procedure whereby a family of existing or newly generated techniques and measures can be applied to determine in advance of actual system development, the impact of new technology on the human resources required for operation and maintenance of the system.

The next task in the conceptualized study approach is envisioned as the most difficult undertaking of the entire effort. This view finds support from a number of sources (Léuba, 1964; Crossman, 1965b; Finley, et al, 1970; and DeGreene, 1974?). Specifically, this next task is that of developing measures and techniques permitting satisfactory levels of quantification of the impact of specific technological innovations on selected human resource parameters. The avenues of approach requiring pursuit are:

- modification of an existing technique for human performance prediction to make it amenable to the present requirement.
- integration of two or more existing techniques to result in a synthesis having applicability to the prediction task.
- development of totally new techniques or measures.

The level of success achieved in this task will influence the remaining study objectives: The application of the resulting measures using the approaches suggested earlier in this report, and an evaluation of the value and utility of the procedure to system designers and planners.

The absence of objective criteria for assessing the procedure dictates a reliance on expert judgment. The use of such a subjective source of evaluation requires great care in the shaping and conduct of the information gathering process. This fact is clearly recognized and as the study progresses, attention will be directed to any plausible way of reducing the subjectivity of the process.

The authors are intimately aware of the exploratory and feasibility nature of the present undertaking. However, the importance of this approach should not be underestimated. As indicated by Darracott et al (1967), "... the current technology race places a high premium on the ability to assess developing technological trends correctly. The pace of this race and the increasing complexity of the problem have exceeded the ability of military forecasters to assess these trends by intuitive methods alone." In the remaining stages of this study, selected avenues of approach will be pursued in an attempt to develop an acceptable method permitting a system designer to conceptualize the probable impact of and manipulate values for selected human resource components in designing cost-effective advanced military systems. Should no method proposed in this study result in a procedural

solution to this decades old problem, it is believed that a contribution nevertheless will have been made by this endeavor in that other researchers will be able to stand on our shoulders in their continuing search for a solution.

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INDEX TO EXPANDED SUMMARIES

† Topic Area

Number	Topic
I	Critical Analysis of Forecasting Methods
II	Impact of Technological Change
III	Simulation Techniques for Relating Technology to Human Resources Impact
IV	Statistical Approaches for Relating Technology to Human Resources Impact
V	Relevance Tree Approaches for Relating Technology to Human Resources Impact
VI	Influence of Human Resource Parameter Information on System Design

APPENDIX

EXPANDED SUMMARIES

Meister, D.,
Sullivan, D. J.,
Askren, W. B.

<u>The Impact of Manpower Requirements and Personnel Resources Data on System Design</u>

The importance of human factors to system performance has been shown a number of times. Both logically and empirically, the negative effect of inadequate consideration of the human element during design can be demonstrated. The contribution of human error to the unreliability of overall system performance has been graphically and empirically illustrated. Evidence is accumulating that the cost of the personnel to operate and maintain a system throughout its useful life is equal to or exceeds that of the hardware. Thus, we have a double-edged problem, performance decrement and high costs, which can be related to the human element of the system. This problem has been made more severe by a history of development of new systems with emphasis primarily on the design of hardware and with little or no regard for the capability or cost of the personnel that will be available to support the system. It has been advocated that one way to reduce the problem is to develop systems with human factors data included as design requirements. This study is, therefore, directed toward a controlled examination of the utility of PRD (Personnel Resources Data) in system design and to the determination of the conditions under which PRD can be effective in influencing that design.

GENERAL RESEARCH APPROACH

The major purpose of this study was to determine the effect on system design of using manpower and personnel resources data as design requirements. Secondary objectives were to determine under what conditions and in what form these data should be used to have maximum effect on design. Equipment, manpower data (e.g., quantities and skill levels), and PRD inputs (e.g., task information) which were produced during the development of the Titan III propellant transfer and pressurization subsystem were adopted and presented incrementally to six design engineers to simulate the Air Force phase 1A/1B development of that subsystem. Subjects were required to create schematics, equipment descriptions and drawings, control panel layouts, operating procedures and bills of material. Cost-effectiveness measures including equipment cost, equipment reliability, human reliability, system safety and design adequacy were applied to the data.

ANALYSIS

The research strategy developed by Meister and Farr (1966) and Meister and Sullivan (1967) involves placing the engineer in a realistic design situation in which he must solve a series of design problems by using informational inputs related to these problems. In adapting this general methodology to the present study, the following steps were performed:

1. Selection of an already operational subsystem which could serve as a model subsystem for the development of test inputs.

2. Selection of appropriate engineer-subjects skilled in design of the type of subsystem selected.

3. Determination of the equipment and PRD inputs which are characteristically provided during the system definition phase of development.

4. Development of manpower and personnel resources data inputs.

5. Determination of the sequence in which these inputs should be provided.

6. Determination of the design responses and outputs which the engineer-subjects should supply in attempting to solve the design problems.

7. Determination of specific measures which could be used to answer the questions which initiated the study.

FINDINGS

1. Manpower requirements and personnel resources data inputs do have an influence on the equipment configuration, but this influence is attenuated by a complex of factors such as the engineer's indifference to and inability to interpret human factors considerations meaningfully; and more importantly, by the inadequate timing of PRD inputs.

2. The potential influence of personnel requirements and PRD inputs on the equipment configuration is much greater than is presently achieved. PRD inputs would exercise much greater effect if they were:

a. phrased as specific design requirements and constraints and included in the SOW (Statement of Work).

b. phrased in concrete design-relevant terms.

3. The manner in which the engineer designs has a significant effect upon his reaction to personnel requirements and his use of PRD inputs, hence on their influence on the subsystem configuration. The engineer's design concept is so quickly developed that traditional timing of manpower requirements and PRD inputs lag that concept. The engineer resists any change to his initial concept as a restriction on his freedom to design creatively.

4. The importance of supplying meaningful manpower information as design requirements in the SOW and subsequent QQPRI analyses by trained human factors personnel, is highlighted by the fact that the engineer's manning concept for his own design does not appear to correspond to the needs of his subsystem designs.

5. The results of this study are in accordance with those of previous design engineering studies. This increases the confidence one can feel in the conclusions derived.

CONCLUSION

It was found that manpower requirements and PRD inputs do influence the equipment configuration, but in this study only moderately, because the

equipment design proceeded so rapidly that incremental PRD inputs inevitably lagged the design. Engineers were responsive only to inputs which were framed as design requirements and which were interpreted in design-relevant terms. Confirming the results of previous studies, engineers were found to be generally unaware of or indifferent to personnel considerations. Different engineers interpreted the same design requirements and assigned priority to design criteria differently. The engineers relied heavily on experience and stereotyped solutions for design answers. The results of the study indicate that manpower and personnel analyses must be performed prior to the issuance of a Request for Proposal (RFP) and not delegated to the development contractor. The contractor must be required to design to a detailed manning structure which is specified in his Statement of Work. Further recommendations are supplied which suggest ways in which Air Force management of the personnel subsystem program should be revised.

Martino, Joseph P. Technological Forecasting for Decisionmaking

This book is intended to provide an advanced treatment of technological forecasting. It is a "how to" book: how to do technological forecasting, how to apply it in specific decision situations, and how to avoid some of the more common errors and difficulties in the preparation of individual forecasts. Although this abstract lists the chapter titles, it is primarily concerned with chapter 9, "Normative Methods."

GENERAL RESEARCH APPROACH

The contents by chapter number are as follows:

1. Introduction
2. Delphi
3. Forecasting by Analogy
4. Growth Curves
5. Trend Extrapolation
6. Analytical Methods
7. Breakthroughs
8. Combining Forecasts
*9. Normative Methods
10. Planning and Decisionmaking
11. Research and Development Planning
12. Research
13. Technology Advancement
14. Product Development
15. Test and Evaluation
16. Technological Forecasting in Business Decisions
17. Technological Forecasting in Government Decisions
18. Technological Forecasting in Social Decisions
19. Some Common Forecasting Mistakes
20. Dangers of Negative Forecasting
21. Evaluating Forecasts as Decision Information
22. Presenting the Forecast
23. The Future of Technological Forecasting

*Chapter 9 covered in this abstract.

The objective of the normative methods is to determine the technological capability which will be required to carry out some function, based on an estimated or projected demand. Exploratory and normative methods are not competitive with, or replacements for, one another. Both are essential, and both must be used together. Normally one does not bother to prepare an exploratory forecast of some technology unless there is a normative forecast (at least an implicit one) that the technology will be needed. Likewise, one does not normally prepare a normative forecast without some idea that it will be possible to meet the goals.

ANALYSIS

The three most common methods of normative forecasting are relevance trees, morphological models, and mission flow diagrams. Relevance trees are used where the system or process being analyzed can be described in terms of

levels of causation, levels of complexity, or levels of hierarchy. Morphological models are used where the system or process can be broken down into elements which can be altered independently, and where there are no hierarchical relationships. Mission flow diagrams are used where the system or process can be described in terms of one or more paths of sequential steps.

1. Relevance Trees

Relevance trees are used to analyze systems or processes in which distinct levels of complexity of hierarchy can be identified. They are developed by carrying out successive identification of increasingly finer components, at progressively lower levels. Each branch divides (at a node) into two or more branches at the next lower level. Each node is a goal for all those branches depending from it. Each goal is satisfied by the achievement of all branches below it and, in turn, derives its validity as a subgoal from the sequence of branches linking it with the top of the tree. Relevance numbers can be assigned to each of the branches of the tree and an overall figure of merit can be associated with a total path through the tree.

2. Morphological Models

"Morphology" describes the study of the form or structure of the entity of interest (i.e., plants and animals in biology, rocks in geology). The essence of the morphological method of analysis is to break a problem down into parts which can to some extent be treated independently, with several solutions or approaches to each. A system or problem is broken down into parts which can be treated independently, and as many solutions or approaches as possible are devised for each part. The technological performance required for each solution is then obtained, and this is used as a goal for the technology involved. Some of the solutions can be rejected immediately on the grounds of feasibility; others can be rejected because of conflicts with other solutions. One is finally left with a set of feasible goals for the technologies involved.

3. Mission Flow Diagrams

The mission flow diagram was originally devised as a means of analyzing certain types of military missions. However, the technique can be applied to the analysis of any sequential process. The technique involves mapping all the alternative routes or sequences by which some mission or task can be accomplished. All significant steps are identified on each route. It then becomes possible to identify the difficulties and costs associated with each route. In addition, it is possible to create new alternative routes, and identify the difficulties and costs associated with these. Once these difficulties and costs are identified, performance requirements can be derived for the technologies involved, and used as normative forecasts.

FINDINGS

1. Normative, or goal-setting methods of forecasting are applied to determine the level of functional capability which must be achieved if some problem is to be solved or some difficulty overcome.

2. Relevance trees are used to carry out analysis of hierarchical structures.

3. Morphological models are used to analyze parallel structures.

4. Mission flow diagrams are used to analyze processes with steps in a spatial, temporal, or logical sequence.

5. Often the same system can be analyzed by either a relevance tree or a morphological model. In such cases, the forecaster should use whichever method is most convenient or appropriate for the problem at hand.

CONCLUSION

The strength of normative methods is that they tend to organize and structure the problem. They can help assure completeness, so that solutions holding some promise are not overlooked. By systematically laying out the structure of a problem, they can assist in the generation of new alternatives which may be superior to those currently in use. Even if all the alternatives uncovered with the use of normative methods prove inferior to those already known, this alone gives additional confidence in the choice of one of the methods as superior to the rest.

It is essential that the normative methods be kept in proper perspective. They are in no sense a substitute for creativity or imagination. They merely provide a systematic means of examining technological requirements.

Hacke, James E. Jr., The Feasibility of Anticipating Economic and Social Consequences of a Major Technological Innovation

Forecasting is methodologically distinct from goal formulation or planning and is as methodologically justified in its use of the results of empirical science as medicine or engineering. On analysis, the methods used for forecasting fall into two major classes, those for forecasting patterns and those for forecasting parameters, with five generically different methods available in each class.

GENERAL RESEARCH APPROACH

The discussion of each method includes description and examples, an investigation of the assumptions underlying its use, an estimate of its range of applicability, and a delineation of its limitations. These methods are applicable alike to technological, demographic, economic, and social forecasting.

Existing literature on past economic and social consequences of major technological innovations rarely go beyond narration and statistical description; they fail to distinguish between changes following an innovation and changes resulting from an innovation. To make this distinction, one must delineate what would have been the course of events if the innovation had not been made. The methods of forecasting can be applied equally well to this delineation of hypothetical consequences.

ANALYSIS

The task of anticipating economic and social consequences of an innovation starts with forecasts of economic and social conditions over the period of time involved and forecasts in their light the probable level of effort likely to be expended in developing the innovation. Then one forecasts the probable pattern of its development and formulates and forecasts the changes in parameters descriptive of its performance. Having this description of the probable future technological development of the innovation, one can forecast probable economic and social impacts. Since these impacts modify the forecast economic and social conditions with which one starts, anticipating economic and social consequences of an innovation is in principle an iterative process.

1. Technological forecasting was studied first under the assumption that methods of assessing economic and social impacts of innovations were much further developed than were those of technological forecasting. However, the reverse proved to be the case.

2. A survey and analysis of the literature on technological (and other) forecasting yielded ten generically different methods of forecasting technological changes.

3. A fundamental approach was to describe relevant portions of the economy and the society following introduction of the innovation and to describe what these might have been had the innovation not been introduced.

Then, one determined the difference between these two descriptions; the difference was a measure of impact of the innovation.

FINDINGS

1. Forecasting is as justifiable epistemologically as engineering, medicine, or any other discipline using the findings of empirical science.

2. The methods of forecasting are basically the same whether applied to technology, demography, economics, or sociology.

3. The division of forecasting into parameter forecasting and pattern forecasting runs through mathematics and science and is therefore probably fundamental.

4. There seem to be five generically different methods of forecasting changes in patterns and five generically different methods of forecasting changes in parameters.

5. Methods of forecasting changes in parameters include statistical measures that give some indication of the precision to be expected. When a parameter passes out of the confidence limits set by these measures, however, the dynamics of the situation are changing and the forecast should be redrawn.

6. The methods of forecasting changes in patterns or structures of organization lack precision or confidence measures and do not preclude alternative courses of development. This constitutes the single most important limitation to the current state-of-the-art in forecasting.

7. The existing literature on assessment of the past economic and social impacts is of limited usefulness for the purposes of this study in that it falls into the <u>post hoc ergo propter hoc</u> fallacy. None of it compares what actually did happen with what might have happened had the innovation not come into existence.

8. The largest single practical difficulty is likely to be locating adequate data for analysis. Data on the transistor through 1956 were not extensive enough to allow projection to 1966. In the absence of data over a long enough time span to establish trends, one must rely solely on informed judgment.

9. The feasibility of anticipating economic and social consequences of a major technological innovation depends strongly on state of technological development of that innovation. Data are scarce in the early stages of developing an innovation, and there may be doubt as to what an innovation actually is and how it works.

10. The specific forecasting techniques used are determined by the nature of the innovation. The transistor is a mass-produced electronic hardware component. Production and cost data were therefore necessary to forecasting of its impact. A software innovation; a process innovation; a low volume, high cost item such as the laser; or a system such as interurban rapid transit would require other kinds of data. Availability of the

required data would determine feasibility of producing a meaningful anticipation of future economic and social impacts.

11. Although the "forecast" of the impact of the transistor and the forecasts suggested are useful as demonstrations, such forecasts would be of more value to planners if they were continuous processes. It would be particularly valuable to monitor a course of development that has been forecast to pinpoint when that course diverges from expectations and to obtain a more rapid check than is now possible on forecasting methods.

CONCLUSION

It is feasible to anticipate the economic and social consequences of a major technological innovation with sufficient detail and reliability to be of major assistance to the long-range planner.

It is not feasible, however, to forecast quantitatively the trends in a parameter or a pattern, with the certainty that the outcome will fall within stated confidence limits. Such certainty would require both exact knowledge of the mathematical form of the trend curve and complete assurance that no perturbation of the trend will occur in the interim.

Anticipating trends in the characteristics of a major technological innovation is feasible. It is feasible to anticipate some of them with enough precision and reliability for the forecast to be of significant value to the planner. The precision and reliability achievable as a function of time may match what the planner needs to know at that time.

On the basis of these anticipated trends in the technical characteristics of an innovation and of its supply and cost, it is possible to anticipate some of its economic and social consequences. In essence, this consists in comparing the probable future course of development in the economy and the society with what would be likely if the innovation had never appeared. Demographic, economic, and social forecasting are feasible to the same extent that technological forecasting is.

Roberts, Edward B. Exploratory and Normative Technological Forecasting: A Critical Appraisal

(This report was contained as an appendix in the Marvin J. Cetron book, Technological Forecasting - A Practical Approach.)

Increased recognition during the present decade of the importance of science and technology to corporate and national existence has produced an intensive search for new methods for managing research and development. The attention being devoted to so-called "technological forecasting" is one manifestation of this concern.

GENERAL RESEARCH APPROACH

This report presents a critical appraisal of the field of technological forecasting. The central theme is that the two phases of exploratory and normative approaches are out of step with each other. Exploratory techniques are too naive and do not take advantage of what has been learned about forecasting in nontechnical areas. Nor do the exploratory techniques reflect what is known about the influences upon the generation of future technology. Normative techniques in contrast are too complex and mathematically sophisticated and cannot justify their elegance on substantive grounds.

ANALYSIS

"Technological forecasting," as defined by those claiming to be its practitioners, is actually two fields, joined more by a vision than a reality. On the one hand is "exploratory forecasting," the attempt to predict the technological state-of-the-art that will or might be in the future, or as Cetron puts it, "...a prediction with a level of confidence of a technical achievement in a given time frame with a specified level of support." Most laymen assume that all of "forecasting" is this kind of forecasting. The second aspect has been called "normative forecasting" and includes the organized attempts to allocate on a rational basis the money, manpower, and other resources that might affect the creation of tomorrow's technological state-of-the-art. Normative forecasting presumably provides aids to budgetary decisions in the technological area. Still more broadly defined by some of its leading exponents, "normative forecasting" applies to a wide variety of attempts to determine policies and decisions that will influence the effective growth of science and technology, in the corporation, the government agency, or the nation as a whole.

Exploratory technological forecasting includes a variety of techniques for predicting the future state of science and technology. Unfortunately, most of the methods are really only variants on simple trend extrapolation procedures, broadly defined, that have limited utility in today's rapidly shifting technological environment. The principal exploratory methods are:

1. So-called "genius" forecasting, based either on individual wisdom or on a group "genius" forecasting process known as the Delphi technique.

2. Formal trend extrapolation to either a straight-line fit or an S-shaped expectation.

The formal trend methods include single-curve projections as well as estimations based on the envelope encompassed by the projection of a family of related curves. They also include both the extrapolation of a single time series as well as the projection of lead-lag relationships between two time series, the latter known as "precursive event" forecasting.

Normative technological forecasting activities attempt to provide a basis for allocating technology-generating resources so as to maximize attainment of organizational goals. The effectiveness of any normative method depends upon the following factors:

1. Meaningfulness of its treatment of goals.

2. Correctness of its assumed relationships between allocated resources and generated technology.

3. Adequacy of its balancing of the resources-to-technology considerations against the worth of goal fulfillment.

4. Implementability of the method, including the ability to acquire reasonable inputs at reasonable costs as well as the ability to persuade organizational decision-makers to use the generated outputs.

Some of the leading normative forecasting techniques are:

1. PROFILE (Programmed Functional Indices for Laboratory Evaluation)

2. QUEST (Quantitative Utility Estimates for Science and Technology)

3. PATTERN (Planning Assistance Through Technical Evaluation of Relevance Numbers)

4. TRW's PROBE II

FINDINGS

1. Comparison of the still evolving approaches to "exploratory" and "normative" technological forecasting yields marked contrasts. In particular, the simple schemes used by those trying to predict the technology of the future look pallid when matched against the sophisticated techniques designed by those who are allocating the resources that will create the future. Exploratory technological forecasts are largely based either on aggregates of "genius" forecasts (e.g., the Delphi technique) or on the use of leading indicators and other simple trend-line approaches. The practitioners of economic forecasting, in contrast, long ago recognized the need for multivariate systems analysis and cause-effect models to develop reliable predictions.

2. Normative forecasting is at the opposite extreme on the sophistication scale, fully utilizing Bayesian statistics, linear and dynamic programming, and other operations research tools. Here, despite the uniqueness, uncertainty, and lack of uniformity of research and development activities, each of the

designers of normative techniques has proposed a single format wholly quantitative method for resource allocation. Along the dimensions of unjustified standardization and needless complexity, for example, the proposed R&D allocation methods far exceed the general cost-effectiveness approach used by the Department of Defense in its program and system reviews.

3. For both exploratory and normative purposes, dynamic models of broad technological areas seem worthy of further pursuit. In attempting to develop "pure predictions" the explicit recognition of causal mechanisms offered by this modeling approach seems highly desirable. This feature also has normative utility, provided that the dynamic models are limited in their application to the level of aggregate technological resource allocation and are not carried down to the level of detailed R&D project funding.

CONCLUSION

There is no doubt that both kinds of "forecasting" are necessary contributors to the technical planning process, and for the military, as well as for most corporations, this technical input is a critical ingredient of an overall business plan. Yet only in theory but not in fact have these two components, the exploratory and the normative, been integrated adequately. Erich Jantsch expresses the logic of and the need for this integration: "Exploratory technological forecasting starts from today's assured basis of knowledge and is oriented towards the future, while normative technological forecasting first assesses future goals, needs, desires, missions, etc., and works backward to the present...The full potential of technological forecasting is realized only where exploratory and normative components are joined in an iterative or, ultimately, in a feedback cycle".

Haines, Donald B.
Gael, Sidney

Estimating Manning Requirements for Advanced Systems: A Survey of the Defense Industry

There is an urgent need for better use of our manpower. An important step is the early estimation of manpower requirements for advanced weapon systems. A simple and accurate method is needed for predicting these requirements as early as possible to prevent a subsequent surprising levy on available men and skills.

GENERAL RESEARCH APPROACH

This research was conducted in an effort to develop techniques of estimating manning requirements while the feasibility of a future system is being studied. One portion of this research program was aimed at identifying and quantifying the relevant variables that generate manning requirements. One goal was to produce a multipurpose estimation technique. System designers could use such a technique to predict manning requirements during the early conceptual phase and trade-off manning requirements with other design constraints and requirements.

ANALYSIS

The defense industry was surveyed to determine their methods and problems of estimating manning requirements. The survey had three principal aims:

1. Determine the different ways the defense industry copes with the problem of estimating manning requirements for future systems.

2. Assess the effectiveness of these methods if they were used with information and data available only during the conceptual phase of the proposed weapon system.

3. Decide which methods are more appropriate to specific kinds of weapon systems.

The questionnaire used in the survey was a five-item, open-ended question type. Respondents were asked to give their name, field of specialization, job title, and the company for whom they were working. The following questions were asked:

1. For which system(s) or subsystem(s) have you participated in the estimation of manning requirements?

2. Describe the technique you have used or would use to estimate the operator and/or the maintenance manning requirements for future systems.

3. Which five factors do you consider to be important determiners of the number of men that will be required to support systems?

4. If you were asked to recommend three publications pertaining to the estimation of manning requirements (either operator or maintenance), which ones would you suggest?

5. Additional comments.

FINDINGS

Questionnaires were sent to 117 people in key defense industries. 75 questionnaires were returned (some completed by a team of respondents). Of these, 55 were fully completed and were answered in a way that was felt to meet the spirit of the survey. The principal findings of the survey are as follows:

1. Dissatisfaction prevails; most industries feel that a new, uniform and standardized method is desired. At present there is no standard method that is applicable in the early stages of weapon system development.

2. Predictions continue to be made so late that they are of little use in influencing design. Often a prediction is made in a form that does not lend itself readily to making design changes.

3. There are definite trends and preferences in current use. Most respondents preferred traditional task-analytic methods for estimating manning requirements and were guided largely by USAF technical reports.

4. The main differences were that the people who had access to acquisition-time data used historic comparison as an estimation technique, while those in the conceptual phase of development had more of a tendency to use other approaches, viz, modeling.

5. Those respondents who had experience with space systems and communications or radar nets used guides other than USAF publications; those with other system experience preferred the USAF guides.

6. In general, the reliance upon USAF guides and materials was heavier in acquisition time. In other than acquisition time, USAF guides were used in conjunction with company reports.

7. There was one significant finding from the statistical analysis: respondents who worked on space systems relied more on mathematical and objective methods of estimation than did those whose experience was with (communication or radar) nets.

CONCLUSION

Five different approaches to estimating manning were reported, the most popular being the use of task analysis or some combination of task analysis with variations of the other approaches. Other methods were: expert estimation, historical comparison, sovereign factors, and mathematical models. The most frequently cited guides were USAF publications, but a wide variety of other texts, handbooks, and technical publications were also reported. Respondent experience ranged over the major weapon systems, subsystems, and control networks.

Barton, H. R., Purvis, R. E., Stuart, J. E., Mallory, W. K.

A Queuing Model for Determining System Manning and Related Support Requirements

Increasing need for earlier estimates of manning, skills, and training requirements led to the development of mathematically sophisticated techniques capable of computing and assessing requirements at every phase of system development. Current methods are largely intuitive, rely on bookkeeping procedures, and are seldom applicable at pre-hardware stages of system development. The method in this report fills a need for making trade-offs when investigating alternatives in system design.

GENERAL RESEARCH APPROACH

The report begins with an analysis of hardware functions and develops human requirements in terms of operational needs and service rates. Manning and skill requirements are integrated over such factors as desired environmental demands, maintenance concepts and procedures, and training requirements. Two mathematical techniques, queuing theory and linear programming, are used to compute manning requirements and training needs.

ANALYSIS

The first step is the development of methods which enable engineers to compute and assess (at a very early time in the systems design) the manning and skill and training requirements for a given system design(s) with accompanying operational and maintenance concepts. This report addresses three areas:

1. Identify significant system variables that affect the requirements for manning, skills, and training.

The approach in this area was based on a mathematical model relating significant variables associated with manning and skill requirements:

a. task identification which determines skill

b. operational performance requirements

The operational requirements were:

(1) operational readiness specified for the system — a condition that must be satisfied.

(2) capability of each operational unit to operate a total number of hours or hours per mission for a certain number of missions per calendar time-unit.

2. Quantify the information about these variables.

For example: Operational readiness (R) = .88
total operational hours (t_0) = 16
number of missions (f) = 8

mission hours (d) = 2
number of equipments (N) = 18

3. Develop mathematical techniques for relating these variables during the conceptual phase of system design and to compute, predict, and/or control the manning and skill requirements.

Because of the need for hardware analysis and operational performance requirements, a causal mathematical model approach was pursued. The mathematical model relates:

a. black boxes and associated repair and failure rates
b. personnel
c. spare black boxes
d. waiting time to make a black box available after demand

The output of the model (waiting time) is related to the system operational requirements and, through application of an algorithm, allows the achievement of minimum manning for specified system operational requirements.

In addition, a method was developed which will allow for scheduling of training-manpower resources in which consideration is taken of the following:

a. training requirements in terms of time necessary to achieve a specified skill

b. phasing-in of new systems and the concomitant demands on available skills

c. phasing-out of old systems and the concomitant availability of skills

d. the manpower phasing into and out of personnel inventory because of enlistment and discharge

FINDINGS

1. It is anticipated that the manning prediction technique in this report does not differ radically from intuitive procedures presently used by management personnel in the Air Force. The recognized differences lie in the formal structure of the manning problem. These differences are:

a. mathematical statement of the manning goal

b. the causal relationship between this goal and manning through the following:

(1) spares

(2) waiting time

2. The manning objective in this report is mathematically equivalent to maximizing the total operational hours of the operational units, given a fixed distribution of skill hours.

3. The objectives are mathematically equivalent to maximizing total training time (of operational units) for a given investment in skill hours.

4. Precise knowledge of operational requirements may not be known and it is desired to know how the manning varies as the operational requirements change. This ability to perform parametric analysis may be important in comparison of alternative systems or in jointly allocating fixed manning resources to two or more systems.

5. The technique will allow evaluation of error in input information through cause and effect relationships developed.

6. Having established causal relationships, required refinement of specific prediction techniques may be directed.

CONCLUSION

Operating procedures must undergo testing and modification to achieve a good usable end product. For a prediction procedure such as the one given in this report, testing should examine various key characteristics such as reliability and validity. A reliable procedure should permit different people to achieve about the same results, given the same inputs. A valid procedure would have as its product, predicted manning close to that which actually is required to do the job. Potential error sources discussed in the report should be subjected to evaluation via a test program for the manning technique. Analysis of causes of errors in predictions could lead to modification of procedures to remedy problem areas.

Test application of the procedure would also provide a check on the clarity and comprehensiveness of the procedures and would point out areas where rewriting or revision is required for ease of application.

Purvis, R. E.,
Mallory, W. K.
McLaughlin, R. L.

Validation of Queuing Techniques for Determining System Manning and Related Support Requirements

System manning has been a persistent problem with all industry and the military services. It has been a particular problem with the Air Force because of the multitude of systems and personnel skill involved. The mathematical model to be validated here is based on finite cyclical queuing theory. Details of the model are contained in a previous report, "A Queuing Model for Determining System Manning and Related Support Requirements."

GENERAL RESEARCH APPROACH

A program was conducted to establish the validity and reliability of a technique of mathematical modeling for predicting manning requirements for weapon systems. The technique was applied to two systems: the F-105D fire control system (FCS), which presently is operational, and the C-141 system, which is scheduled for operation in the near future.

ANALYSIS

Before a decision is made that a predictive mathematical model is acceptable, a validation is needed. The ways in which a prediction model may not meet stated objectives are:

1. The model may include superfluous independent variables which have no appreciable effect on the dependent (output) variable.

2. The model may omit significant independent variables.

3. The model may assert an inaccurate, incorrect, or inadequate functional relation between the dependent variables. This may be the case for only certain ranges of values of one or more of the independent variables.

4. A valid model apparently may fail due to inaccurate parameter predictions. That is, inaccurately predicted values of an independent variable, substituted into the model, may yield an incorrect value for the dependent variable; whereas accurate predictions would have yielded an acceptable value.

5. Every mathematical model of a real system is an approximation. An extremely accurate approximation is possible by taking many independent variables into account and using accurate values for these variables. If some of the variables are neglected because of poor model construction, or because they are not measurable, the approximation can be inaccurate. Therefore, it is necessary to decide in advance what degree of accuracy will lead to model acceptability. In general, sophistication and refinement of models are subject to diminishing returns, so that each further improvement bought at the same cost in technical effort will yield a smaller improvement in accuracy. Accordingly, it is desirable to attempt model sophistication only commensurate with desired accuracy.

The points discussed above form the fundamental criteria used in the validation of the model evaluated for manning prediction capability undertaken in this program.

FINDINGS

1. The manning technique evaluated in this program has been demonstrated to be a valid and reliable technique for predicting manning requirements for weapons systems.

2. The technique has been found to be relatively easy to apply, and is compatible with existing methods for predicting reliability and maintainability parameters.

3. The model is based on random processes approximating field conditions, and produces valid results using state-of-the-art reliability and maintainability techniques.

4. The prediction for the FCS, using field data as sources for parameter estimation, yielded good results when compared with operational performance and existing manning.

5. The results of the FCS analysis also verified the fact that, as with any technique, the validity of this technique depends upon the accuracy of the inputs.

6. There is also evidence in the program results that the technique provides a means for seeking out sources of inefficient personnel utilization and sparing procedures.

7. It has been agreed that the reliability of a model lies in the ability to produce consistent results with different experimenters.

8. The validation program did not formally test for reliability; however, a method was developed which establishes a general procedure for achieving reliability. This procedure was found to be quite sensitive to, and dependent on, methods for estimating parameter values and organizational structure of the support system.

CONCLUSION

The model prediction for the FCS, using field data for parameter estimation, yielded good results when compared with operational performance. Moreover, it was shown that the operational performance could be achieved by 34% fewer personnel than the manning set by the table of organization. The model prediction for the FCS, using conceptual data, resulted in substantially the same manning for the maintenance shop as that developed from the measured data; but, because maintenance concepts had been changed in the field, the number of flightline airmen was larger than the measured data. The manning prediction for the C-141 system, based on operational rates planned for the system and field data on the C-130 system, resulted in a prediction of 819 airmen in the organizational maintenance squadron and 476 airmen in field maintenance squadron. With the predicted manning it could be expected that an operational readiness of 78% could be maintained.

Snyder, Melvin T., Askren, William B. — Techniques for Developing Systems to Fit Manpower Resources

This report discusses four related processes for developing systems within manning and skills constraints. The point is made that the military services are beginning to feel the need to exert some measure of control over system design where human resources are involved.

GENERAL RESEARCH APPROACH

The report covers: (1) research to demonstrate that certain human resources data, such as manning and skills data, when used as design constraints along with other constraints does affect system design; (2) techniques by which to match or balance, through trade-off practices, the hardware, the human and other system support or logistic functions in order to get a best mix depending on the real world operational goals; (3) a new specification by which personnel requirements are stated in terms of system requirements, for integrating more fully the human requirements with the system engineering processes; (4) a newly developed computer based data handling system for human resources data in the conception, development, test and operation of systems. The new data handling system is also an integrator of human and hardware data within and across systems, and a mechanism for comparing field performance data with early design data.

ANALYSIS

A study was conducted:

1. to determine the effect on system design of using certain human factors data, in this case, manpower and skills data as design requirements.

2. to determine under what conditions these inputs could be made to have maximum influence on system configuration.

The study simulated the design of the Titan III Propellant Transfer and Pressurization Subsystem (PTPS) by gathering the equipment and personnel documentation produced during the Titan III PTPS development and distilling them into the key inputs which has been provided to the original designers.

Six highly experienced propellant system designers were selected as subjects and given the problem of designing the PTPS, starting from the Statement of Work. As equipment inputs, they received the information the original designers had received — functional requirements, equipment specifications, and hardware information. They also received in the Statement of Work a manpower constraint which required them not to exceed a certain crew size and skill level. In addition, they received incrementally other personnel resources inputs such as task sequences, human error data, and task time limits.

During the test period, the engineer subjects were required to develop all the outputs they would ordinarily be required to produce in actual design: schematics, equipment descriptions, operating procedures, control panel

sketches, lists of required hardware. The detail these engineers provided was great enough so that at the end of the testing period the subsystem designs could be evaluated by mathematical systems effectiveness measures, including equipment reliability and safety.

In additon, at the end of each test session, the engineers were interviewed intensively to determine whether in their opinion the personnel data inputs were useful to them and if the data had influenced their design.

FINDINGS

1. Manpower and personnel skill data can have an influence on system configurations. Examples of this influence are given in the report. The three designers with a design goal of a small crew with high skill produced top-level schematics averaging 4.7 human functions, and the three designers with a design goal of a large crew with low skill produced top-level schematics averaging 7.0 human functions. The "small crew" designers averaged 58.7 and the "large crew" designers averaged 68.0 for quantity of items of equipment to be operated by personnel. Finally, the "small crew" designers produced configurations that required on the average 6.0 personnel to provide operation and maintenance, whereas the "large crew" configurations required 8.3 personnel.

2. The design approach followed by an individual engineer has a significant effect upon his reaction to the manpower and personnel skill data. The engineer's design concept is so quickly developed, based on his own past experience, that traditional incremental timing of the human factors inputs lags that concept. The engineer resists any change to his initial design as a restriction on his creative freedom.

3. The potential influence of manpower and personnel skill data inputs on system configuration is much greater than presently recognized or achieved. The inputs would exercise much greater effect if they were (a) included in the Statement of Work as design contraints, and (b) phrased in concrete relevant terms.

CONCLUSION

This research has been successful. Several companies have studied this "pilot" system and have put similar processes into their own operations. The first purpose for this research has been attained — that was to develop and test computer techniques and design a "pilot" model for subsequent development into a data handling system. Based on this research, a proposed Advanced Development Objective, "Automated Information and Data Handling for System Program Offices" (AIDSPO) was prepared recently and is under consideration as a development program.

Meister, David,
Finley, Dorothy L.,
Thompson, Ernest A.

Relationship Between System Design, Technician Training and Maintenance Job Performance on Two Autopilot Subsystems

Human resources requirements and data, particularly those related to training, have little significant impact upon equipment configuration. Having knowledge of equipment design, training, and experience factors does not necessarily provide information on how they influence performance. The study described in this report was aimed at providing information on how these variables are interrelated.

GENERAL RESEARCH APPROACH

The study was designed to discover certain characteristics of equipment design which affect training time and performance level. The specific purposes of the present study were to determine:

1. Those design characteristics of the selected subsystems which the maintenance technician responds to in performing maintenance.

2. How effective maintenance is on the selected subsystem.

3. How technician effectiveness is related to particular design characteristics.

4. What differences in maintenance performance are related to differential amounts of experience, training, and skill level of personnel.

5. What parameters of skill maintenance personnel recognize as differentiating various levels of skill and how these relate to the 3, 5, 7 level categories used in the Air Force.

6. Whether the study methodology is effective and those modifications which should be made to improve the effectiveness of the study methodology.

ANALYSIS

After the airborne electronic equipments in the inventory were reviewed, two autopilot systems were selected for study.

1. Subjects for the study were those technicians assigned to autopilot maintenance at two Air Force bases.

2. The study methodology involved direct observations of technicians performing troubleshooting type maintenance.

3. Following each maintenance incident, technicians were interviewed about the incident.

4. At the conclusion of the study, maintenance supervisors ranked and rated all technician subjects on a series of specially constructed scales.

5. Data collectors also rated the major characteristics of the equipment maintained. These ratings were correlated with indices of technician performance.

6. The resultant correlations were subjected to multiple regression analysis, and those factors contributing a significant amount to performance variance were extracted.

As a possible substitute for prolonged observations, a subjective report test battery was developed to permit subject personnel to report their own maintenance performance. This battery was administered at the conclusion of the study to all technician subjects and to two classes of autopilot maintenance students.

FINDINGS

1. The performance data sought to determine the relationship between indices of maintenance behavior and various classes of predictor variables. After the variables which influenced maintenance performance were identified, they were organized into factors by interpreting their interrelationships. These factors are:

a. Accessibility

(1) to the equipment on which maintenance must be performed.

(2) within the equipment to be maintained.

b. Diagnostic information represented by

(1) the information supplied directly from the equipment being maintained.

(2) the information derived from test equipment used to check out the equipment.

(3) information from T.O.'s and checklists.

c. Equipment structure consisting of

(1) chassis weight and dimensions.

(2) number, type, and arrangement of internal components.

d. General technician capability, particularly for

(1) test equipment usage.

(2) maintenance function and procedures.

2. The data obtained from the experimental test battery indicate that experienced maintenance technicians can reliably predict certain aspects of maintenance performance.

3. Technicians can reliably estimate troubleshooting task times, task difficulty, and diagnostic strategy required by the maintenance problem.

CONCLUSION

Four general factors were found to be primarily responsible for the maintenance performance observed. The factors were accessibility, diagnostic information, equipment structure, and general technician capability. A residual experience factor was also found. From the results of the administration of the subjective report test battery, it seems feasible for maintenance technicians to predict maintenance duration of failure problems with which they are familiar, the relative difficulty level of these problems, and the order in which they troubleshoot these failures.

If the conclusions reached are to be accepted with any confidence, they must be replicated with a larger number of maintenance personnel and different equipments. Verification of the hypotheses raised by this study can be accomplished by selecting equipments from the Air Force operational inventory which vary systematically in terms of the general factors found and then collecting maintenance performance data on those equipments, making use of the experimental test battery procedure. In addition to this, methods must be developed for obtaining better information on training parameters than current Air Training Command records provide.

Lintz, Larry M.,
Loy, Susan L.,
Hopper, Raymond,
Potempa, Kenneth W.

Relationships Between Design Characteristics of Avionics Subsystems and Training Cost, Training Difficulty, and Job Performance

The human resources of the Air Force have a major impact on the operational capabilities and overall costs of systems. However, information on human resources requirements is generallv introduced late or not at all into system design. Previous studies by the Air Force Human Resources Laboratory indicate such information does affect design if it is available in suitable quantitative form early in design and if the Statement of Work requires that it be used. This study investigated the relationship between avionics subsystem design characteristics and training time, training cost, and job performance.

GENERAL RESEARCH APPROACH

A list of design variables believed to affect training and job performance was established and supplemented with personnel variables. Twenty-nine measures of the equipment design were taken, ranging from the number of test points to the number of throw-away components. The personnel variables used were aptitude test scores and amount of training and experience. Thirty functional loops, from ten avionics subsystems, were selected as the units of equipment to be investigated. Functional checkout procedures were identified or constructed for each functional loop. Ten Air Force (AF) students were observed performing each of the functional checkouts; performance time, Technical Order (T.O.) reading time, and errors were recorded. Training time and training equipment cost data were collected for each loop. Regression analyses and factor analysis were used to analyze the results and derive equations to predict training time, training equipment cost, and job performance time and errors from equipment characteristics.

ANALYSIS

A functional loop in this study is defined as a network of circuits and equipment units within an avionics subsystem through which signals are processed to perform a specific function.

The principal requirements for a correlational study of equipment characteristics influencing maintainability can be summarized as follows:

1. Establish a comprehensive and valid listing of design characteristics for inclusion in the study.

2. Sample across classes of equipment so that the results of the study can be generalized to a range of practical equipment items.

3. Collect as comprehensive a data base as possible using the best methods available.

The general approach for this study was designed with these criteria in mind. To meet time and cost limitations in this probe, restrictions had to be

imposed, but these were chosen to maximize the data base and the generalizability. The items of equipment which were investigated included navigation, flight control, communications, and fire control systems (30 functional loops within 10 different avionics subsystems).

Thus far, the most satisfactory method of collecting maintenance performance data is observation by observers who are familiar with the tasks they are scoring. The data base therefore, for this report, consisted of on-site real-time observations of performance by experienced data collectors.

The major task was the functional checkout procedure since a complete functional checkout can be specified for each functional loop of the equipment, and the functional checkout is the first stage of troubleshooting. The checkout verifies that the reported malfunction is indeed present, that it is in the loop under investigation, and within that loop identifies the area of malfunction.

The study was carried out in three broad phases: first, determine the design characteristics to be included and select subsystems and functional loops to represent those characteristics; second, collect data; and third, analyze results.

FINDINGS

1. Four prediction equations were developed through the use of stepwise regressions.

2. Ninety-four per cent of the variance in maintenance task performance time can be accounted for by the complexity of the subsystem, the number of steps in the maintenance task, the reliability of the test equipment used, and the ruggedness of the components being repaired.

3. Ninety-four per cent of the variance in task errors was found to be due to the number of steps in the maintenance task; the number of special conditions, such as cooling, that are required; extent to which the T.O. uses standard symbology; the amount of training; the number of dependent remotely located components; and the reliability of the test equipment.

4. Eighty-one per cent of the variance in training time required for a task could be accounted for by the convenience of test point location, the length of the task, whether T.O. change data are clearly presented and the number of dependent remotely located components.

5. Seventy-seven per cent of the variance in the cost of training equipment could be accounted for by the extent to which maintenance tasks are automated, the per cent of identical circuits used and the T.O. time.

6. A factor analysis, using the orthogonal components method, resulted in identifying 6 factors which account for a major part of the variance in the 20 independent variables which correlate significantly with performance. Names assigned to the 6 factors are:

a. Length of Checkout Procedure

b. Equipment Complexity

c. Difficulty of Checkout Steps

d. Nonautomatic Checkout

e. Diagnostic Information

f. Clarity of Information

7. Stepwise regressions of the performance variables on the factors resulted in prediction equations with multiple correlation coefficients of 0.92 or greater.

CONCLUSION

The magnitudes of the regression coefficients establish this as a very promising approach to deriving human resources data for systems under development. This has been shown to be true across a variety of avionics equipment, including communications sets, autopilots, air data computers, and fire control systems. The degree of predictive accuracy attained in this study cannot be expected to remain as high during replications of this study. However, the results of this study indicate that even with normal shrinkage the predictive capability of the equations will remain highly significant.

Lintz, Larry M.,
Loy, Susan L.,
Brock, Gerald R.,
Potempa, Kenneth W.

Predicting Maintenance Task Difficulty and Personnel Skill Requirements Based on Design Parameters of Avionics Subsystems

The human resources of the Air Force (AF) have a major impact on the operational capabilities and overall costs of systems. However, information on human resources requirements is generally introduced late or not at all into system design. Previous studies by the Air Force Human Resources Laboratory indicate such information does affect design if it is available in suitable quantitative form early in design and if the Statement of Work requires that it be used. This study investigates the relationship between avionics subsystem design characteristics and task difficulty, personnel skill characteristics, and job performance.

GENERAL RESEARCH APPROACH

The relationships among subsystem design characteristics, personnel skill characteristics, and job performance were investigated for avionics subsystems. A list of design characteristics was established, based on expert opinions of avionics engineers, Air Force supervisors, and instructors. Functional loops and line replaceable units were selected from ten subsystems representing navigation, flight control, communications, and fire control subsystems. Experienced maintenance supervisors identified high skill and low skill maintenance personnel. The same supervisors associated performance times and error probabilities with these personnel for three maintenance tasks — an easy task, a difficult task, and a complete functional checkout task. Supervisors also rated each task on a scale of difficulty. Both stepwise regression and factor analysis were used to derive equations for predicting performance time, error probability, and design characteristics. Similar analyses derived equations relating performance time and errors to personnel characteristics. Personnel factors of Experience, Aptitude, Breadth of Skills, Motivation, Training, Time in Grade, and non-Air Force Technical Education were identified.

ANALYSIS

This study used a correlational approach to derive equations for predicting performance times, errors, and task difficulties from equipment design characteristics and personnel characteristics. Organizational level maintenance data were collected on 27 functional loops from 10 avionics subsystems (a functional loop is defined as a network of circuits and equipment units within an avionics subsystem through which signals are processed to perform a specific function). Intermediate level maintenance data were collected on 28 line replaceable units (LRU's) from the same 10 avionics subsystems.

Twenty-eight (for organizational level maintenance) and 29 (for intermediate level maintenance) equipment design characteristics, such as number of test points and accessibility of components, were measured objectively from the equipment itself or from the Technical Order (T.O.). Where

objective measurement was not possible, rating scales were completed by AF personnel. Sixteen personnel variables, such as aptitude scores, amount of training, and military rank, were used.

Three maintenance tasks were identified for each functional loop and LRU — an easy task, a difficult task, and a functional checkout task. For each task, experienced AF maintenance supervisors estimated performance times and error probabilities for their high skill and their low skill personnel. Supervisors also rated each task on a scale of difficulty.

The design, personnel, performance, and difficulty variables were intercorrelated, and were entered into regression and factor analyses. Equations were derived to predict performance and task difficulty from design characteristics, and to predict performance from personnel variables and task difficulty. Personnel factors and design factors were identified. Personnel profiles were developed for high and low skill groups. Plots of performance versus difficulty and task completion versus time were developed.

FINDINGS

1. The multiple correlation coefficients (Rs) for predicting times from design characteristics ranged from 0.87 for high skill personnel performing intermediate maintenance to 0.93 for low skill personnel performing intermediate maintenance, indicating that from 75 to 86% of the observed variance in performance times can be accounted for by as few as 2 or as many as 8 predictor variables such as number of steps in checkout procedure, accessibility of components, use of identical circuits, and level to which checkout is carried (LRU, module, or component). The Rs for the error equations ranged from 0.59 for high skill personnel performing organizational maintenance to 0.85 for low skill organizational maintenance, with 1 to 4 predictor variables accounting for 36 to 72% of the observed variance in error probabilities.

2. The equations for predicting task difficulty of functional checkout procedures from equipment design characteristics gave Rs of 0.73 at organizational level (53% of the variance) and 0.80 at intermediate level (64% of the variance), from 4 predictors.

3. Regression equations for predicting performance times from task difficulty and 1 or 2 personnel characteristics yielded Rs of 0.50 for high skill intermediate maintenance to 0.73 for high skill organizational maintenance (25 to 53% of the variance). The corresponding equations for error probabilities from 3 to 5 predictors yielded Rs from 0.59 for high skill organizational maintenance to 0.78 for low skill organizational maintenance (36 to 62% of the variance).

4. Factor analyses on the performance and personnel variables isolated factors of Length of Service, Aptitude, Experience, Motivation, Air Force Technical Training, and Time in Grade, at the organizational level. At the intermediate level, the factors were Length of Service, Aptitude, Electronic Aptitude, Avionics Experience, and non-Air Force Technical Training.

5. Factor analyses of design variables indicated that factors associated with maintenance performance times and error probabilities were Checkout

Complexity, Checkout Information, Length of Checkout, Accessibility, Equipment Complexity, and Test Equipment and Adjustments.

6. Personnel profiles for the 16 personnel variables were developed for each subsystem and for each maintenance level; at organizational and at intermediate maintenance levels the low skill profiles have approximately 6 times the error probability of the high skill profiles.

7. Plots of time and errors as functions of difficulty level indicate accelerated relationships. High and low skills are more clearly separated in errors than in performance times.

CONCLUSIONS

The results of the present study should be replicated and extended across additional subsystems and types of avionics equipment. The performance measurement methods should be validated, and a better technique for determining error probability should be developed. The relationship between task difficulty and the performance measures should be further investigated and clarified.

Crossman, Edward R.F.W., Laner, Stephen — The Impact of Technological Change on Manpower and Skill Demand: Case-Study Data and Policy Implications

The research in this report represents an expansion and development of earlier work by the present authors reported in October 1966 under the title "Evaluation of Changes in Skill Profile and Job Content Due to Technological Change: Methodology and Pilot Results from the Banking, Steel and Aerospace Industries."

GENERAL RESEARCH APPROACH

The overall objective of this report was to analyze manpower and skill impact of technological change. The specific objectives were:

1. Apply the skill-profile methodology developed in the course of previously reported pilot investigations to direct labor in further types of technological change, thereby enlarging the available data base and permitting more positive conclusions to be reached.

2. Extend the methodology and/or modify it to obtain parallel data for indirect labor in a subset of the processes studied.

3. Provide an overview of the manpower demand pattern indicated by the data and draw conclusions relative to manpower policy.

ANALYSIS

1. Outline of the "Skill Profile" method

The "Skill Profile" is the distribution of total man-hours required to produce a unit product (or service) along the scale from least to most highly skilled labor. A suitable basis for the construction of such skill scales has been established using skill factor scores derived from job evaluation schemes used in most industries. Comparison between skill profiles of newer and older processes permits statistically controlled conclusions to be drawn concerning the impact of technological change on manpower and skill requirements, provided that precautions are taken to control the effects of the following factors:

a. processes to be compared must be matched for the nature and quality of their material inputs and outputs.

b. they must be in a steady state to avoid contamination by transiently increased man-hour and/or skill requirements due to process development, debugging, etc.

c. organizational differences between firms must be controlled by replicating each comparison in at least two firms.

Paired comparisons of the manpower and skill demand pattern before and after a specific technological advance can be made fully quantitative by the

statistical technique of analysis of variance. The effect of central interest in the present study was the (skill level x technology) interaction which was tested for significance against the residual variance in the (skill level x technology x firm) interaction term. When the variance ratio was significant at a selected confidence level, it was inferred that the observed change in skill profile had been caused by the technological change studied.

2. Selection of further direct-labor case studies

The skill profile method previously developed was applied in further direct-labor studies on technological changes in electricity generation, oil refineries, air separation, and airline passenger reservation systems. As before, these cases were each selected as being typical of a large class of similar technological changes in the same and other industries. In each case a fairly recent and pronounced technological advance had become stabilized and was deemed likely to replace the older technology in the near future.

3. Extension of the "Skill-Profile" method to indirect labor

A criterion of "Process Relatedness" was adopted to determine or identify the indirect labor force. Included were those functions whose withdrawal would cause a rapid decay in process performance. Indirect labor was traced and allocated to unit production with the inclusion of maintenance and first level supervision, planning and scheduling, and the exclusion of technical and research personnel and higher management.

Although difficulties were encountered in acquiring data for indirect labor skill profiles, the feasibility of applying the skill profile method was established, and complete (direct plus indirect labor) profiles were obtained for a sizeable subset of the total case-study complement.

FINDINGS

1. Labor Productivity

   a. Labor productivity increased in 72% of cases, and remained the same in 28%; direct labor productivity was not reduced by any of the technological changes.

   b. Greatest gains were recorded where the prechange technology required the greatest amount of direct human intervention in the process.

   c. In most cases (88%) inclusion of indirect labor data reduced the productivity gains computed from direct labor alone.

   d. There was substantial variance between organizations due to identical (or near identical) technological changes.

2. Changes in Skill Profile

   a. The limited amount of indirect-labor data that could be acquired within the resources did not permit statistically controlled

comparisons between pre- and post-change skill profiles for the total process related work force.

b. Mean direct labor skill levels increased in 50% of comparisons, remained unchanged in 33%, and declined in 17%.

c. Direct labor data results support the view that technological advance tends to increase skill demand.

d. On the average, technological change tends to decrease the skill demanded on the process-related work force in manufacturing and service industry.

e. Skill increases observed in the direct labor force were largely cancelled out by decreases at indirect labor level.

f. Increases in overall skill level are associated with technological advance only in the service sector, where labor demands are relatively low.

3. Impact of Technological Change on Work Force Educational Levels

With only one exception, the newer technology required a better educated labor force than the old. The general nature of the process had more effect than the technological change in itself.

CONCLUSION

It has become clear from the studies completed on a pilot basis that direct labor data taken alone yield a misleading picture of the overall manpower and skill impact of a given technological change. It is necessary to emphasize conclusions based on total data where these are available, even though for lack of replication they were not tested for statistical significance. Further research effort would be needed to round out and substantiate the present conclusions by completing the 18 comparisons undertaken.

Other factors were not fully investigated within this report. Of these, the most important is probably the relative effectiveness of manpower utilization across processes and technologies.

Askren, William B.,
Korkan, Kenneth D.

Design Option Decision Trees: A Method for Relating Human Resources Data to Design Alternatives

The human resources of the Air Force have a major impact on the operational capabilities and overall costs of aerospace systems. One of the research objectives of the Air Force Human Resources Laboratory is to develop methods of incorporating human resources data (HRD) in the decisions which define system design characteristics. This study was performed to determine the feasibility of predetermining the design options available to the engineer as he progresses through a design problem.

GENERAL RESEARCH APPROACH

It would be most useful if a method could be developed for relating human resources data to detailed design features. These data could then enter into decisions regarding selection of specific design options. The purpose of this investigation was to determine the feasibility of identifying the design options available to the engineer as he progresses through a design problem. The approach involved three steps:

1. Design options available to the engineer in the propulsion and flight control subsystem areas were identified and placed in decision tree form.

2. Design options and the concept of arranging the options in decision tree form were evaluated by eight engineers experienced in design of these classes of subsystems.

3. The information and data obtained from the engineer evaluators were analyzed (after personal interviews), and new decision trees of the propulsion and flight control areas were prepared to represent a composite of their recommendations.

ANALYSIS

Two experienced engineers worked together to produce five first generation decision trees describing propulsion and flight control subsystems. Eight engineers were chosen as evaluators; four with experience in propulsion, and four with experience in flight control. Each evaluator was given a set of the decision tree drawings related to his area of experience and asked to study and critique them. After a few days, an interview was held with each of the evaluators. During the interview the engineer was questioned concerning his opinion of the validity of the design options and the flow and nature of decisions represented in the tree. He was also asked for his evaluation of the completeness of the tree with respect to the design options available in the subsystem area, and the feasibility and practicality of representing the available options in a decision tree format. And finally, he was asked to recommend changes to the tree in order to represent the design decision process according to his experience. The information and data obtained from the evaluators were analyzed, and new decision trees of the propulsion and flight control areas were prepared to represent a composite of their recommendations.

FINDINGS

1. Feasibility and Practicality of Preparing Design Option Decision Trees

It was found to be feasible and practical to prepare design option decision trees, to identify the major disciplines or subsystems of an aeronautical system, and to further determine the delineation of design options relevant to the subsystems.

2. Validity and Thoroughness of Design Option Decision Trees

All eight evaluators judged that the originally prepared decision trees were valid representations of the design decision process, and, although not complete, adequately demonstrated the concept. The second generation trees were developed after recommended expansions and changes were given by the evaluators. Although design option decision trees can be made initially utilizing one or two people, it is necessary and feasible to incorporate the consensus of a number of experienced engineers to develop the final concepts.

3. Relating Human Resources Data to Design Options

All eight evaluators judged that the design options should be meaningfully evaluated for human resources factors such as maintenance difficulty, personnel skill, training difficulty and manpower costs, as well as for engineering parameters such as reliability, development costs, performance, and weight.

4. Computer Processing of Design Option Decision Trees

Recently developed computer software allows the storage and retrieval of tree forms of data. It is therefore highly likely that design option decision trees can be processed by computer. Computer software must be expanded to include the capability of storing the human resources implications of the design options. This would allow the design engineer to work through a design problem at the computer console with computer memory providing the human resources (or engineering) implications of the design alternatives under consideration.

5. Other Uses of Design Option Decision Trees

A number of other applications of the decision tree format for design information were identified:

a. The decision tree format clearly indicates the number of choices available to the engineer at each decision node.

b. It shows the interrelationships of decisions.

c. The format allows for describing advancements to the state-of-the-art at the decision points.

d. It provides a priority sequence of the decisions.

CONCLUSION

The preparation of design option decision trees for propulsion and flight control subsystems was found to be feasible and practical. Although design option decision trees can be made initially utilizing one or two people, it is necessary and feasible to incorporate the consensus of a number of experienced engineers to develop the final concepts. Design options can be meaningfully evaluated for human resources factors such as maintenance difficulty, personnel skill, training difficulty and manpower costs, as well as for engineering parameters such as reliability, development costs, performance, and weight. It was also determined that the design option decision trees can be processed by computer. This would allow machine storage and retrieval of the many design options and the related human resources data which could be used to evaluate each option.

Askren, William B.,
Korkan, Kenneth D.,
Watts, George D.

Human Resources Sensitivity to System Design Trade-off Alternatives: Feasibility Test with Jet Engine Data

Historically, skilled maintenance personnel were provided for Air Force weapon systems after the hardware was delivered to the operational command. Maintenance personnel selection and training was accomplished as a form of reaction to the demands of the equipment. Today, because of system complexity and the faster pace of events, human resources planning is characterized by analyses which predict maintenance manpower needs early in system development life. This allows personnel selection and training to begin before the hardware is delivered to the field.

GENERAL RESEARCH APPROACH

The feasibility of developing Design Option Decision Trees to a level of detail which shows hardware involved in "on-aircraft" maintenance, and the feasibility of measuring the sensitivity of human resources data to design trade-off problems depicted in these trees were investigated. The approach included expanding a portion of an earlier developed aircraft jet engine tree, selecting trade-off problems from the expanded tree for sensitivity analysis, and collecting psychometric data from experienced jet engine mechanics regarding this sensitivity. Five Design Option Decision Trees were developed for turbofan jet engines. Eight turbofan trade-off problems were evaluated for effect on human resources. The factors of training and experience, and amount of troubleshooting time (as affected by choice of design option): ease of maintenance; complexity of tools and equipment; and crew size and job specialty were examined.

ANALYSIS

1. A portion of the aircraft propulsion Design Option Decision Tree developed in the earlier study was selected for expansion.

2. An attempt was made to develop turbofan jet engine Design Option Decision Trees down to a level of detail depicting the smallest item of hardware replaced during "on-aircraft" maintenance. This is comparable to the maintenance four-digit work unit.

3. A number of design option trade-off problems representing a variety of jet engine characteristics were selected for sensitivity analysis as to their effect on Human Resources Data.

4. Psychometric data were collected from experienced jet engine mechanics as a means of measuring the human resources sensitivity. Data were obtained regarding the effect of the design options on maintenance crew size, maintenance job specialties, training and experience, troubleshooting time, ease of maintenance, and complexity of tools and equipment.

FINDINGS

1. It was found feasible and practical to prepare Design Option Decision

Trees detailed to the maintenance four-digit work unit level of detail for turbofan jet engines.

2. Five trees were developed and include a top-level drawing that shows the relationship of turbofan jet engines to the propulsion subsystem.

3. Four trees were developed that describe the design options for jet engine assembly, jet engine installation, and jet engine supporting systems.

4. The levels of detail in the trees are sufficiently varied (such as choice of type of fan, choice of type of starter system, choice of type of compressor bearings) to provide trade-off problems with a variety of hardware characteristics.

5. Eight trade-off problems were selected for study regarding effect on human resources. Six experienced jet engine maintenance mechanics evaluated the design options:

a. The results show that the amount of training and experience required for troubleshooting a failure is significantly affected by choice of design options in six of the eight problems, with as much as 60% less training and experience being required for the favored options.

b. Amount of time required to troubleshoot a failure is significantly affected by choice of design options in six of eight problems, with as much as 56% less troubleshooting time required for the favored options.

c. The complexity of tools and equipment required to troubleshoot a failure is affected in two of eight problems.

d. Overall ease of maintenance is significantly affected by choice of design option in five of eight problems.

e. Crew size and job specialty required to troubleshoot a failure are each affected in one problem.

6. The combined results indicate that at the start of a subsystem design effort the required design trade-off problems can be identified and evaluated for impact on the human resources.

CONCLUSION

It is concluded that it is feasible to develop Design Option Decision Trees to the maintenance four-digit work unit (line replaceable unit) level of detail, thus providing a description of the broad spectrum of trade-offs that would be performed during a subsystem design. It is concluded that it is feasible to determine the sensitivity of human resources data to trade-off problems and design options using psychometric analysis methods. It is concluded that selection of a design option will influence human resources and maintenance factors for a substantial proportion of design trade-off studies. Finally, it is concluded that in trade studies with more than two options to consider it is highly probable that an order of priority of design options based on human resources effects can be determined.

Thomas, Ralph E.,
Pritsker, A. Alan,
Christner, Charlotte A.,
Byers, Richard H.

The Effect of Various Levels of Automation on Human Operators' Performance in Man-Machine Systems

Many systems must be monitored at regular intervals and maintained within specified tolerance limits. A pilot, for example, must monitor the speed and position of his aircraft and keep within some limits of heading and altitude. The necessity for controlling these system processes arises because they are subject to disturbances both erratic and constant. In other words, the system process is subject to a noise component superimposed on a signal which, on the average, drifts out of the specified tolerance.

GENERAL RESEARCH APPROACH

This report describes a method for generating definitive data on the effects of various levels of automation on human operators' performance in man-machine systems. The method incorporates a model and equipment for theoretical and experimental investigations. Equipment was designed and built in accordance with the assumptions of the automation model for studying human performance in an automation environment. Functions to be controlled are generated by a general-purpose analog computer.

ANALYSIS

The conceptual model which is used contains three essential elements: the noise parameter, the drift parameter, and the tolerance limits for the variable to be controlled. In addition, the model contains two essential human parameters: the monitoring frequency and the subjective tolerances. These subjective tolerances are perceptual limits which may or may not be the same as the actual tolerances. They are included to permit the human to correct the system whenever he thinks it is necessary. He may, for example, make a corrective action based on his subjective estimate when the system actually is not out of control. These subjective tolerances form the specifically human inputs to the model, are variable from subject to subject, and vary from time to time in a given subject. They are also subject to change due to motivation, drive, competition or cooperation, fear, fatigue, and other complex psychological factors. In addition, these tolerances are subject to change by the degree of uncertainty the subject feels about his ability to control the system.

The model allows the designer to incorporate human performance properties into the control subsystem by providing methods to determine the following relationships: first, how noise and drift are associated with subjective tolerances, and second, how complex psychological factors are associated with these tolerances. Knowing these relationships, the designer can modify his equipment to conform to human requirements, or personnel can be selected on the basis of the adequacy of their subjective tolerances to control a specific system.

In the model, the tasks of the human are repetitive cycles of three types of assessments for the control of the system. He must determine whether or

not the system is in control, select the corrective action to restore or maintain control, and judge the effect of the corrective action. The analysis is thus reduced to manageable proportions by focusing on the correctness of the assessments and the manner in which they are made under various conditions.

The conceptual model can be used to describe almost all man-machine systems. These systems have at least four elements. First, they have some type of input. Second, these systems have a capacity to process information. Third, all of these systems are expected to perform some task; that is to say, they have an output. The fourth element is provision for control of the system. Each system has criteria of performance associated with it. The control subsystem takes the kind of action necessary to enhance the attainment of the performance criteria.

Functions to be controlled are generated by a general-purpose analog computer. Automatic recording of input and response signals for all three assessment types is accomplished on a six-channel recorder. In addition to having separable panels to permit future studies of different organizations of groups of human operators, the equipment may be preprogrammed to simulate failure by making certain correction controls "inactive" at specified times.

ANALYSIS

1. The critical experiments showed that the equipment is suitable for conducting automation experiments. In addition, the effects of parameter variations of the stochastic model yielded results generally as expected.

2. Three pilot experiments were conducted that involved changes in the parameters of the stochastic model, the level of automation, the subjects' task, and the assessment cycle time.

3. For each experiment, a description of a hypothetical, but realistic, problem was given to the subject. Preliminary training sessions were conducted to introduce the automation environment to the subject, to explain the experiment, to describe the equipment and its use, and to specify the task to be performed. At the completion of each experiment, a questionnaire concerning the experiment was answered by the subjects.

4. In Experiment 1, the subject could not predict the behavior of the relevant system variable because of a large random component included in the stochastic model. Thus, the decision rules adopted by the subjects did not appear to involve prediction. Because the decision rules programmed into the machine also omitted prediction, no significant differences between human and machine performance were detectable for the various levels of automation.

5. In Experiment 2, the parameters of the stochastic model were changed in order to increase the predictability of the relevant variable. Moreover, the levels of automation for the Type I (is the system in control?) and Type II (select corrective action to restore or maintain control) assessments were altered in such a manner that the overall level of automation was not changed; hence, no significant differences in performance scores among the various levels of automation were observed.

6. In Experiment 3, two of the extreme levels of automation used in Experiment 1 and the stochastic model of Experiment 2 were used, and a significant difference in performance scores was observed. A quantitative comparison of the theoretical and observed results for Experiment 3 could not be made because the magnitudes of the corrective actions were not suitably chosen in this experiment. However, qualitative agreement with the model was fully demonstrated.

CONCLUSION

The efforts in this research program have produced the following tangible results:

1. A qualitative model in which the automation problem is reduced to its essential features.

2. A quantitative model that includes two system parameters, and may be analyzed to determine the assessment cycle times that will yield a desired probability of control for given tolerance limits, and specified magnitudes of the corrective actions.

3. An experimental apparatus that is capable of presenting to groups of subjects a wide variety of control problems characterized by the specific values used.

4. The results of pilot experimental studies that suggest satisfactory agreement between the predicted and observed probabilities of control.

Buechner, William R. Technological Change and the Occupational Composition of the American Labor Force, 1950 - 1960

Technological change is one of the most important factors affecting the American labor force, but as yet one of the least understood. The kinds of models used by economists to examine technological change have been among the primary sources of this lack of understanding; they tend to focus on two-factor models and examine questions concerning, e.g., whether or not there is a labor-saving bias connected with current technological change. This report examines the effects of technological change on the occupational composition of the U.S. labor force between 1950 and 1960 using an input-output model, with each industry's labor input coefficient disaggregated into 240 occupational coefficients.

GENERAL RESEARCH APPROACH

This report utilizes an input-output model to measure the effects of changes in:

1. The level and composition of final demand

2. The input-output coefficients

3. Labor productivity in each industry

4. The occupational coefficients in each industry on the economy's total employment by occupation.

The model is used to measure the effects of technological change on the kinds of jobs performed, the level of complexity, and their educational and training requirements. The model is used to determine whether the occupational substitutions which occurred as a result of technological change were affected by changes in the relative wages of the different occupations.

ANALYSIS

Three questions were confronted:

1. How did technological change between 1950 and 1960 affect the economy's demand for labor from individual occupations? Also, given the fact that technological change can work to alter a number of different kinds of labor-demand variables, which facets of technological change were most important in determining occupational employment trends?

2. Is it important for manpower planning to ask how technological change affected the kinds of work performed in the economy's jobs, the content level of that work, and the educational and training requirements?

3. Did the wage changes between 1950 and 1960 induce factor-substitution through technological change or was technological change autonomous?

A model was made to answer these questions. The model was a modified input-output model developed by Wassily Leontief. It was assumed that the production functions for the economy's industries are of the fixed-input-coefficient form, with not only intermediate inputs, but labor inputs as well, proportionately related to output levels. The model was implemented with input-output data from the 1947 and 1958 input-output studies and with employment by occupation by industry matrices from the 1950 and 1960 Census of Population. Adjustments were made to the original data to correct for the different time periods used and for different industry categories used in compiling and reporting the data. The final model was implemented using 65 industries and 240 occupations.

FINDINGS

1. Each of the possible sources of change had much different effects on labor demand, totally as well as on individual occupations.

2. Final demand changes worked to increase the demand for labor from all but four occupations; the average unweighted increase was 33.6 per cent with very little variation among occupations.

3. Technological change worked to reduce labor demand from most occupations, but its effect was very diverse.

4. Most importantly for manpower planning, it appears that the main source of variation in the growth rates of employment by occupations is to be found in the changes which individual industries made in the occupational mix of their labor inputs.

5. Variation in occupational demand was due to technological change, and more specifically, to occupational mix changes.

6. Changes in the final demand vector were not significant factors in altering the pattern of work performed in the economy; the only jobs which experienced much faster than average rates of growth from this variable were those involved with work in the fields of health, education, welfare, and research and design.

7. Technological change, however, did measurably affect the kinds of work performed, reducing employment in jobs associated with tools and machines while increasing demand for labor in service-oriented jobs.

8. Final demand and technological changes were both important factors in raising the overall content of the economy's jobs; both worked to increase the economy's demands for jobs involving high content levels and to decrease demand for low content jobs.

9. Technological change over the decade tended to increase the amount of education required for jobs, by increasing demand for occupations needing a high school education or more and decreasing demand for those requiring less than 12 years. There was no discernible effect on job training requirements.

10. Final demand changes had effects on educational and training requirements which were similar to those of technological change.

11. Technological change was generally factor-biased, with most industries substituting rising wage occupations for falling wage occupations.

12. Anticipated wage changes were a significant variable in the choice of technology, but accounted for very little of the variation among occupational substitutions.

CONCLUSION

It is possible to use an input-output model to examine the effects of technological change on the occupational composition of the labor force. These changes include level and composition of final demand, input-output coefficients, labor productivity in each industry, and the occupational coefficients in each industry on the economy's total employment by occupation.

The degree of accuracy with which these changes can be measured is not, however, determined.

Crossman, Edward R. F. W.,
Laner, Stephen,
Davis, Louis E.,
Caplan, Stanley H.

Evaluation of Changes In Skill-Profile and Job-Content Due to Technological Change: Methodology and Pilot Results From the Banking, Steel and Aerospace Industries

A new method has been developed for measuring the impact of selected advances in technology on the distribution of skills required in the direct labor force in manufacturing and service industries. Based broadly on the "direct productivity" studies conducted by the Bureau of Labor Statistics in the late forties and early fifties, the procedure as applied to a single process entails evaluating the man-hours of direct labor expended per unit product at each of several skill levels and thence computing skill-based productivity measures and mean skill level.

GENERAL RESEARCH APPROACH

Established job-evaluation schemes used by firms for deriving basic pay rates provided the essential data for assessments of skill-level, a quantitative skill-scale being obtained by grouping point scores for selected factors: the point scores for a single process fall into a distribution termed a "skill-profile." Mean skill-levels were computed from the skill-scale point scores multiplied by man-hours per unit product and summed over all workers employed on the process. The standard deviation and range of skill-levels, and other rele ant statistics were also computed. This enabled comparisons to be drawn between the skill-profiles obtained for two or more levels of production technology.

ANALYSIS

Case material was carefully selected and controlled for the comparisons to reveal only the differences in manpower and skill requirements due to changes in process technology and not to other irrelevant factors. Two (or more) processes were matched in respect of the dimensions, quality specifications and other relevant characteristics of raw materials and finished product. Processes were in a steady state, with a criterion that two or more years' productive operation had been applied to avoid transient effects.

Random error (uncontrolled variation) is needed to test observed differences for statistical significance. This was obtained by replicating each matched-pair comparison in a different firm or organization, matching the raw materials and product as closely as possible, and also technologies of the older and newer processes operated by the two (or more) firms or organizations.

When controlled data for two or more such pairs of processes have been obtained it becomes possible to test observed changes in mean skill-level for statistical significance by analysis of variance of the man-hour data. Variations ("main effects") due to skill-level, technological level and firm are removed first, and the interaction between skill-level and technological level is then tested for significance against the three-way interaction between skill-level, technological level and firm. Thus, fully quantitative conclusions can be drawn from a small number of sample observations, provided

that a minimum of four matched processes are studied (i.e., two or more technological levels in each of two or more firms).

FINDINGS

1. In each case the introduction of more highly mechanized production methods was associated with substantial reductions in total man-hours required per unit product (direct labor). Productivity increases ranged from 26.5% to 271%.

2. A given process showed closely similar patterns, both of unit labor requirement and of change with technological advance, when operated in different firms and organizations.

3. Different processes showed statistically significant differences in skill requirement and different patterns of change with technological advance.

4. The skill-profiles for the older technologies in banking and steel processes showed a preponderance of middle-level skills, while in aerospace machining processes higher levels predominated. It may plausibly be surmised that the absence of lower-level skills is associated with the fact that the older processes were already highly mechanized.

5. The reduction in per unit labor requirements due to introduction of new processes was concentrated in the middle range of skills, except for aerospace machining where the higher level skills showed most reduction.

6. Mean skill-levels were increased to a statistically significant extent in all cases except aerospace machining (where they were reduced significantly). However, the changes recorded were all small both in relative and absolute magnitude.

7. Absolute per unit labor requirements in the skill groups were reduced in all cases except demand-deposit accounting and galvanizing. Even in these two instances the increases were small in terms of full time job equivalents. Thus, the evidence does not support the widely expressed view that advanced production technology substantially raises the requirement for highly-skilled operating personnel.

8. The overall impact of the advanced technologies studied was a small net increase in mean skill level due to a larger reduction in middle-level than in higher-level skills.

The above results were confirmed by assessment of educational and job-experience requirements which were found to rise very little with advancing technology. However, these changes could not be tested for statistical significance.

The diversity of skill-content (as distinct from skill-level) was assessed by a count of job-types, and the results indicate greater diversity in one case only, demand-deposit accounting. Job diversity showed little change in manufacturing industry.

CONCLUSION

The present study has served to develop a quantitative methodology for studying manpower and skill in relation to technological change and for analytically forecasting employment by industry and skill-level. It has also provided pilot results from three distinct areas of modern industry which have traditionally employed a direct labor force of significant size. Further studies in different industries and on different types of processes will greatly strengthen the confidence attaching to the conclusions on automation, skill, and manpower outlined in this report.